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CITRUS FERTILIZER EXPERIMENTS

By

S. E. COLLISON

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CITRUS FERTILIZER EXPERIMENTS

By S. E. Collison

The judicious use of commercial fertilizers in the orange grove has been one of the important problems confronting the Florida citrus grower. In the expense involved and the effects upon the tree and fruit, this problem ranks as of equal importance with any of the other operations in the grove, such as spraying, harvesting, pruning or cultivation. At the time when the work reported in this bulletin was begun, practically no experimental work in this line had been carried out in the state. The existing knowledge of the effects of the various fertilizers in use was entirely the result of the practical experience of the growers themselves and was of a more or less conflicting nature. In order to obtain accurate knowledge of the effects of various fertilizers over a comparatively long period, the experimental work discussed in this bulletin was undertaken. A young grove was located on Lake Harris, about three miles from Tavares, in Lake county, and used for the experiment. The piece of land was selected with special reference to protection from cold, adaptability to citrus culture and uniformity of type of soil. It is generally considered that the influence of the fertilizer treatment given citrus trees may extend over a period of several years after that particular treatment has been discontinued. In order to eliminate this disturbing factor from the experiment it was deemed advisable to begin with young trees. Accordingly, one year old budded trees, all of the same variety, especially selected with regard to uniformity of size, and all from the same nursery, were used in the work. They were set out in January, 1909, three-quarters of a pound of bone meal being given each tree.

OBJECTS OF THE EXPERIMENT

The objects of the experiment were to determine the effects of various fertilizers upon the chemical composition of the soil, upon the growth and composition of the trees and upon the fruit. The effects of lime and other alkaline materials, and of various cultural treatments upon the soil and upon the trees were also objects of study. To supplement the work in the grove with fertilizers, a number of soil tanks were made use of on the horticultural grounds of the Experiment Station.

PLAN OF EXPERIMENT

The grove was divided into 48 plots of ten trees each. These trees were Valencia Late on sour stock, and were set 15 by 30

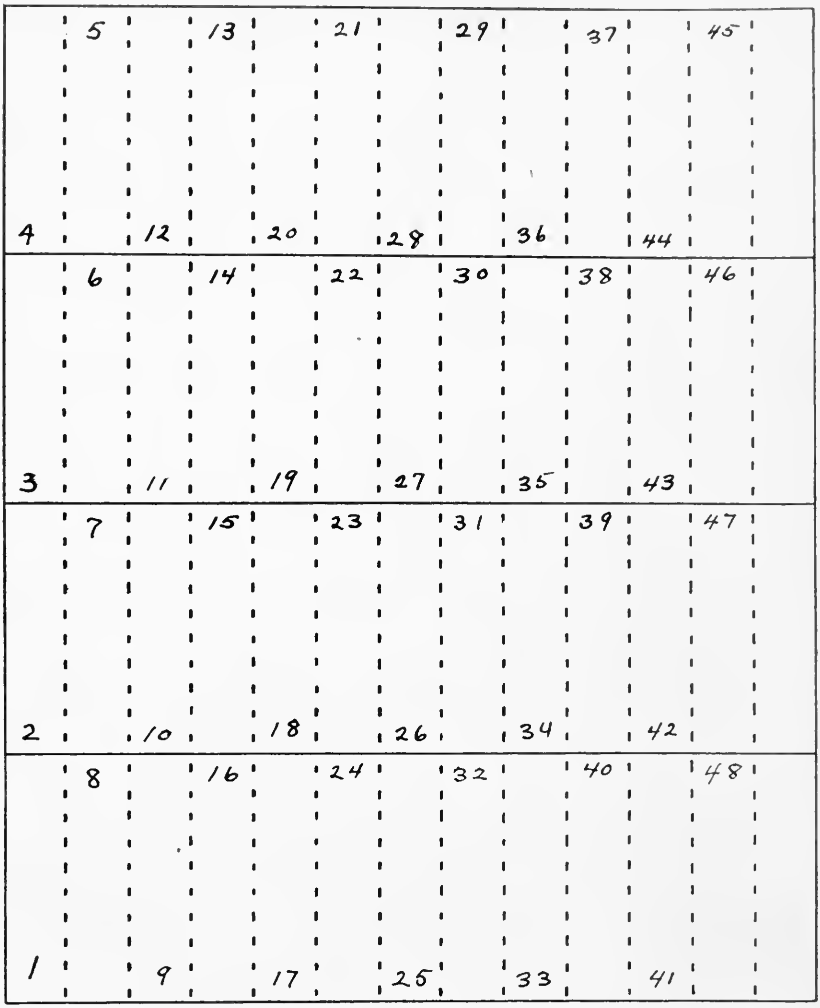

Fig. 1.—Diagram of plots in the ten year fertilizer experiment

TABLE 1.—FERTILIZER MIXTURES USED

An application of two pounds per tree was taken as the standard amount.

Standard formula (for young trees)	Ammonia, 5 per cent., from sulphate of ammonia. Phosphoric acid, 6 per cent., from acid phosphate. Potash, 6 per cent., from high-grade sulphate of potash.

Variations from the Standard

Plot 1. Half the standard.
Plot 2. Standard.
Plot 3. Double the standard.
Plot 4. Four times the standard.
Plot 5. Phosphoric acid and ammonia increased by one half.
Plot 6. Phosphoric acid and potash increased by one half.
Plot 7. Ammonia and potash increased by one half.
Plot 8. Phosphoric acid and potash decreased by one half.
Plot 9. Phosphoric acid and ammonia decreased by one half.
Plot 10. Ammonia and potash decreased by one half.
Plot 11. Standard and finely ground limestone.
Plot 12. Standard and air-slaked lime.
Plot 13. Standard and mulch.
Plot 14. Standard.

Sources of Nitrogen

Plot 15. From nitrate of soda.
Plot 16. Half from nitrate of soda, and half from sulphate of ammonia.
Plot 17. From dried blood.
Plot 18. Half from sulphate of ammonia, and half from dried blood.
Plot 19. Half from nitrate of soda, and half from dried blood.
Plot 20. From cottonseed meal.
Plot 21. From cottonseed meal. (With ground limestone.)
Plot 22. Half from cottonseed meal, and half from sulphate of ammonia.
Plot 23. Half from cottonseed meal, and half from nitrate of soda.

Sources of Phosphoric Acid

Plot 24. From dissolved boneblack.
Plot 25. From steamed bone.
Plot 26. From steamed bone. (Double amount.)
Plot 27. From Thomas' slag. (Nitrogen from nitrate of soda.)
Plot 28. From Thomas' slag. (Double amount. Nitrogen from nitrate of soda.)
Plot 29. From acid phosphate. (Potash, 7½ per cent. in June, 7½ in October, and 3 in February.)
Plot 30. From acid phosphate. (Nitrogen from nitrate of soda. Potash from hardwood ashes.)
Plot 31. From acid phosphate. (Standard.)
Plot 32. From dissolved boneblack.
Plot 33. From floats.
Plot 34. From floats. (Double amount.)
Plot 35. From floats. (Four times amount.)
Plot 36. From floats. (Four times amount. Nitrogen from cottonseed meal.)

Sources of Potash

Plot 37. From low-grade sulphate.
Plot 38. From muriate.
Plot 39. From high-grade sulphate of potash. (With ground limestone.)
Plot 40. From kainit.
Plot 41. From high-grade sulphate of potash. (Standard.)
Plot 42. From nitrate of potash. (Balance of nitrogen from nitrate of soda.)

Variations from the Standard

Plot 43. No fertilizer.
Plot 44. Standard.
Plot 45. Standard and mulch.
Plot 46. Standard and clean culture.
Plot 47. Nitrogen from dried blood. Clean culture.
Plot 48. Nitrogen from nitrate of soda. Clean culture.

feet. The diagram in Figure 1 shows the relation of the plots to each other. The fertilizer and other treatment given these forty-eight plots is shown in Table 1. A standard formula consisting of 5 percent ammonia, 6 percent phosphoric acid, and 6 percent potash, was used. In the fall this was changed to 2½ percent ammonia and 8 percent potash, the phosphoric acid remaining the same. The standard mixture consisted of sulphate of ammonia, acid phosphate, and high grade sulphate of potatsh. As shown in Table 1 this mixture was varied for different plots by substituting other sources of the three essential elements for those in the standard mixture. The standard mixture was used at first at the rate of 2 pounds per tree three times a year. This amount was gradually increased so that at the end of the experiment the "standard" plots were receiving an application of six pounds instead of two.

TABLE 2.—COMPOSITION OF GROVE SOIL. ANALYSIS OF COMPOSITE SAMPLE

	Soil	Subsoil
Insoluble matter	94.09	94.81
Volatile matter	2.55	1.71
Nitrogen	.033	.018
Phosphoric acid	.10	.09
Potash	.047	.025
Soda	.134	.115
Lime	.13	.17
Magnesia	.14	.09
Manganese oxide	.10	.14
Ferric oxide	.98	.96
Aluminum oxide	2.30	2.40
Sulphur trioxide	trace	trace
Carbon dioxide	none	none
	P2O5	N
1st foot	.12	.030
2nd foot	.10	.015
3rd foot	.09	.013
4th foot	.09	.012
5th foot	.09	.009

Plots 46, 47 and 48 were cultivated during the entire year. Plots 13 and 45 were mulched with a mixture of forest leaves, grass, etc. The remainder of the grove was cultivated up to the rainy season (about June 1), and then a cover crop allowed to occupy the land until in September, when it was either turned under or cut for hay and the stubble plowed under. During the early years of the experiment this cover crop consisted of beggarweed. The soil finally became too acid to support a good crop of the beggarweed, and was at first supplemented with cowpeas, and later on with velvet beans.

TABLE 3.—NITROGEN AND PHOSPHORIC ACID IN SOIL

	A	B	C	D	E	F	G	Ave.
N	.029	.040	.033	.033	.037	.030	.028	.033
P_2O_5	.09	.12	.08	.11	.12	.10	.09	.10
SUBSOIL								
N	.018	.018	.015	.020	.019	.018	.016	.018
P_2O_5	.09	.12	.08	.09	.11	.08	.08	.09

The effects of the various treatments on the trees were measured by taking at regular intervals the diameter of the trunks six inches above the bud. Notes on the size, general appearance and character of growth of the trees were taken from time to time.

COMPOSITION OF SOIL

The soil on which the grove is located is a rather coarse reddish sand of the hammock type, verging on high pine, and rather dry in character. At the time that the trees were set out composite samples of the soil (0-9 inches) and of the sub-soil (9-21 inches) were taken and analyzed. In one place in the field samples of the first five feet were taken and the phosphoric acid and nitrogen contained in the samples were determined. These analyses are given in Table 2. Samples of the soil and subsoil were also taken in seven different places in the field and analyzed for phosphoric acid and nitrogen. These analyses are given in Table 3. They show that the soil over the field was of a fairly uniform composition. The analyses of this soil as a whole indicate that it is somewhat above the average in fertility as compared with citrus soils in general.

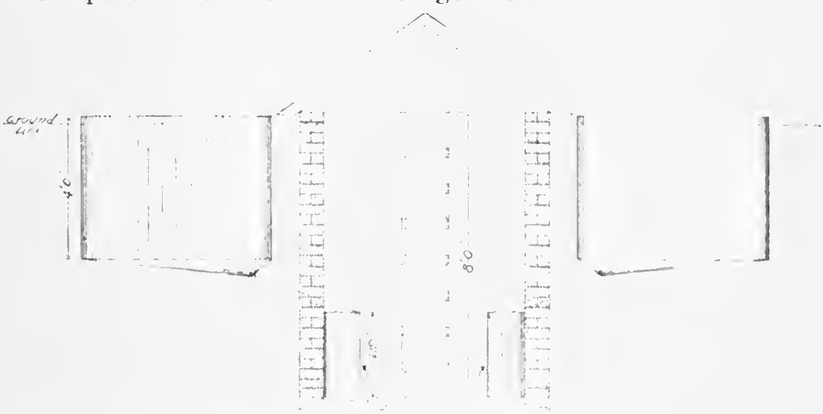

Fig. 2.—Sectional view of tanks

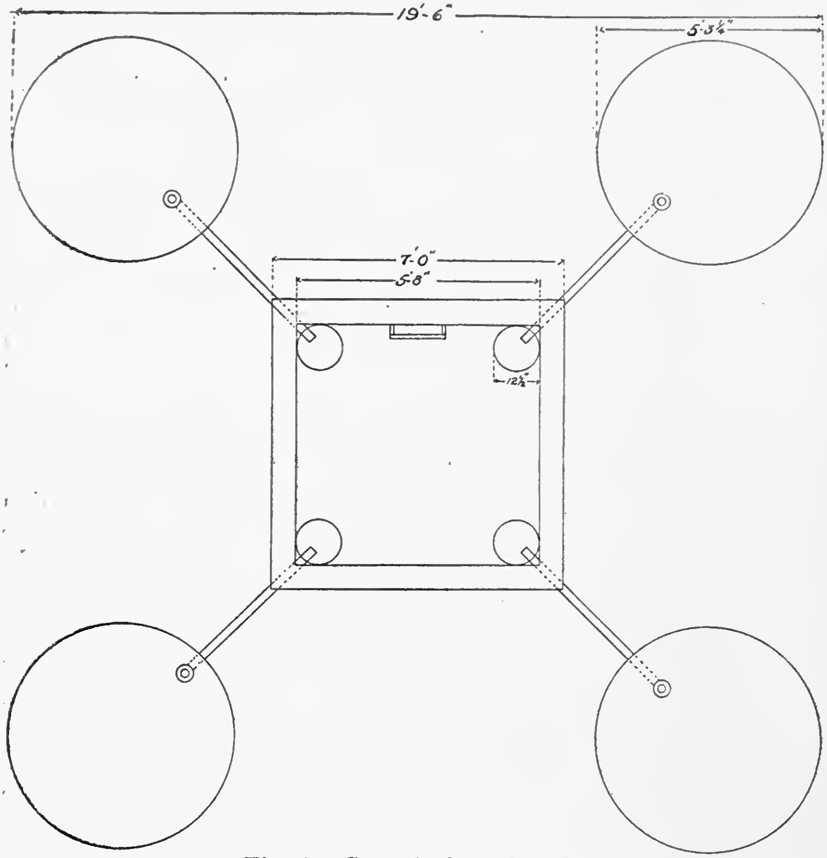

Fig. 3.—Ground plan of tanks

LEACHING OF FERTILIZER

In order to supplement the work with fertilizer in the field, soil tank experiments were begun on the Station grounds. By this means it has been possible to more closely measure and control conditions than where the work has been conducted on the scale necessary in field experiments. Accurate estimates of the losses of fertilizing materials in the drainage water under different systems of fertilizing and the effect of long continued use of fertilizers on the soil have been possible. In this way much interesting light has been thrown upon the question of the capacity of the average sandy Florida soil for retaining the fertilizing ingredients added to it and which of these materials are most subject to leaching.

Figures 2 and 3 illustrate the equipment used in the work. The tanks were constructed of heavy galvanized iron, painted

inside and out with a chemically-resistant paint. Each tank had an inside diameter of 5 feet 3¼ inches, with a maximum depth of 4½ feet, and a surface area of one two-thousandths of an acre. As shown in the diagram, the bottom of the tank slopes to one side, where there is a strainer opening into a two inch tin-lined iron drainage pipe, the length of which is a little over 4 feet. Four such tanks open into a central collecting pit as shown in Figure 3. Under the ends of the drainage pipes entering at the four corners of the pit were placed large galvanized cans for collecting the drainage waters. These cans were coated on the inside with paraffine to prevent any chemical action of the drainage water upon the metal. The collecting pit, which is about 8 feet deep and 6 feet square inside, is built of brick, with a concrete bottom, and is covered. The soil tanks were sunk in the ground to within a few inches of the tops and were filled with soil to within 3 inches of the rims. The soil used was a rather coarse, gray sand of high hammock type. It is described by the Bureau of Soils as Norfolk sand. In filling the tanks a layer of quartz pebbles was first placed over the sloping part of the bottom in order to provide adequate drainage and to prevent the soil from sifting thru the strainer and filling the drainage pipe. Above the layer of pebbles was placed 45 inches of soil. In excavating for the tanks the soil was removed in layers. First a 9 inch layer was removed and placed at one side by itself. Then the soil was removed in one foot layers, each foot being kept separate from the remainder. The last foot of excavated soil was placed in the bottom of the tank, then the remaining sections ending with the top 9 inches. Thus the soil rested in the tank as it was in the original state. Each layer of soil was well packed as it was placed in the tank, the same weight of dry soil, 8,625 pounds, being used in each. The tanks were then exposed to natural conditions, the drainage water leaching thru the soil being collected from time to time as it became necessary, and analyzed. This treatment was continued for a period of 10 months during which time the soil received no fertilizer, the results obtained representing the losses of plant food from a bare, unfertilized soil. The results show that by far the greatest loss of plant food falls on the nitrogen of the soil. The thoro aeration which the soil received when the tanks were filled would lead to more rapid nitrification of the soil organic matter and thus to somewhat larger losses of nitrogen in the drainage water at first, than would occur under natural condi-

TABLE 4.—LOSS OF NITROGEN FROM SOIL TANKS

Water sampled	Grams of N. added	Sulphate of Ammonia			Nitrate of Soda			Dried Blood		
		N. lost	N. in soil	Percent N. lost	N. lost	N. in soil	Percent N. lost	N. lost	N. in soil	Percent N. lost
July 13	74.74	.63	74.11	.85	2.28	72.46	3.05	1.47	73.27	1.96
Aug. 23	....	1.18	72.93	1.59	11.32	61.14	15.63	4.16	69.11	5.68
Sept. 5	....	4.66	68.27	6.39	20.34	40.79	33.28	11.98	57.13	17.34
Nov. 22	18.69	8.46	78.49	12.40	22.07	37.41	54.21	16.59	59.22	29.05
Jan. 8	....	8.12	70.36	10.35	13.26	24.15	35.44	9.35	49.87	15.80
Mar. 12	37.37	5.72	64.64	8.13	2.56	21.59	10.59	2.06	47.81	4.13
April 13	....	3.91	98.09	6.05	3.46	55.50	16.04	.43	84.75	.90
June 10	37.37	10.14	87.95	10.34	11.63	43.87	20.95	2.10	82.65	2.48
July 16	....	9.64	115.68	10.96	7.94	73.29	18.10	1.99	118.02	2.41
Aug. 23	....	6.43	109.25	5.55	....	73.29	....	....	118.02	....
Oct. 21	18.69	3.19	124.75	2.92	3.46	88.52	4.72	1.38	135.33	1.17
April 1	37.37	.65	161.46	.52	4.23	121.65	4.78	.97	171.72	.72
July 14	37.37	1.61	159.85	1.00	2.38	119.28	1.95	.27	171.45	.16
Aug. 9	....	....	197.23	....	....	156.65	....	....	208.82	....
Oct. 31	18.69	2.53	213.38	1.28	2.17	173.16	1.39	.22	227.28	.11
Jan. 3	....	1.72	211.66	.80	.43	172.73	.25	.16	227.12	.07
Jan. 24	....	.56	211.09	.27	.29	172.44	.17	.27	226 85	.12
Feb. 11	....	.59	210.50	.28	.84	171.60	.48	.32	226.53	.14
Mar. 6	37.37	.79	247.08	.38	.93	208.04	.54	.34	263.57	.15
Aug. 8	37.37	2.33	282.12	.94	4.25	241.16	2.05	.27	300.66	.10
Oct. 10	....	3.12	279.00	1.11	1.20	239.96	.50	....	300 66	....
Oct. 23	18.69	....	279.00	....	....	239.96	....	.25	300.41	.08
Dec. 21	....	2.26	295.42	.81	2.22	256.42	.92	.41	318.69	.14
Jan. 6	....	2.28	293.13	.77	1.52	254.90	.59	.25	318.44	.08
Jan. 25	....	2.03	291.10	.69	1.63	253.27	.64	.52	317.92	.16
April 5	37.37	1.49	289.60	.51	.86	252.41	.34	.45	317.47	.14
May 17	....	1.02	288.58	.35	....	252.41	....	....	317.47	....

tions. Allowing for this factor, however, the losses of nitrogen still remain very large. During the 10 month period a loss of nitrogen equivalent to over 800 pounds nitrate of soda per acre was noted. The losses of potash and phosphoric acid were much smaller, in fact, almost negligible. The loss of potash per acre amounted to about 14 pounds, and phosphoric acid to about a half pound. These figures show that these two elements of plant food are locked up in the soil in relatively insoluble forms which become only slowly available. At the end of this period of 10 months, an orange tree was placed in each tank and fertilized with a fertilizer of the same formula as that used in the grove experiment. The trees in all the tanks received the same amounts of phosphoric acid and potash in the form of acid phosphate and high grade sulphate of potash, the source of nitrogen only being varied. The trees in tanks 1 and 2 received sulphate of ammonia, the tree in tank 3 nitrate of soda, the tree in tank 4, dried blood,

the same amount of actual nitrogen being used for each tree. The same amount of fertilizer as was used in the grove was applied to each tree three times per year. The results of the analyses of the drainage water collected from these tanks from time to time are given in Table 4. These figures indicate the extent to which the nitrogen of the three materials used leaches thru the soil. These losses are stated here in percentages of the total amount of nitrogen applied less the amounts lost on preceding dates. For example, the table shows that on November 22, 1911, the drainage water from the nitrate of soda tank contained an amount of nitrogen equivalent to over 54 percent of the total nitrogen which had been applied up to that date, less the quantity of nitrogen already leached out up to the same date. In other words, the percentage of loss for each date was figured on the amount of nitrogen still remaining in the soil at that date, and not on the total amount which had been applied.

LOSS OF NITROGEN

A study of the table brings out a number of interesting and important facts. It will be noted that while the loss of nitrogen varies with the material used, the percentages lost with all three materials increase from the beginning up to November 22, and continue large until August, 1913. For the period from July 13, 1911 to July 17, 1913, 41 percent of the sulphate of ammonia applied to the soil leached thru and was lost in the drainage water; 72.5 percent of the nitrate of soda, and 38.3 percent of the dried blood were lost. This interval of about two years represents a period during which the trees were becoming established and when the root system was small and occupied but a small portion of the soil. Consequently, much of the fertilizer was not utilized and as a result leached thru the soil and was lost. The fact that the losses became smaller as time went on indicates that the larger root systems were able to utilize more and more of the fertilizer. The table also brings out important differences in the behavior of the three different sources of nitrogen in the soil. It will be noted that the largest loss of nitrogen occurred with the nitrate of soda, the losses from the other two sources being considerably less. The larger loss of nitrate of soda is explained by the fact that this material is very readily soluble in the soil moisture and that the soil has very little if any power to retain or fix nitrogen in the nitrate form. Consequently, if the soil is moist and the rainfall is

sufficient to more than saturate the soil the nitrate of soda is immediately dissolved and much of it is carried below the range of the plant roots. Dried blood and sulphate of ammonia differ from nitrate of soda in their behavior in the soil.

The nitrogen in these materials is not available for plants until it is changed to the nitrate form thru the agency of various soil bacteria in the process known as nitrification. In its original form the nitrogen of dried blood is not readily soluble in the soil water, and consequently very little is lost in the leaching process until nitrification occurs. In this change the organic nitrogen of the blood is changed first to ammonia, then to the nitrite and finally to the nitrate form, when it becomes as readily soluble as the nitrate of soda and is leached out as readily. Nitrification of the dried blood is a gradual process, extending over a period of time which may be of several weeks' duration, depending on soil conditions. Because of this, some of the nitrogen of dried blood, or for that matter, any similar organic material, will remain in the soil a considerably longer time and be available to the crop over a longer period, than nitrate of soda. This is especially true where heavy rains occur after the latter has been applied to the soil.

The behavior of sulphate of ammonia in the soil is different from either of the two materials already discussed. While this substance is readily soluble in the soil water the soil has the power of fixing or absorbing at least a portion of the ammonia, thus preventing it from leaching away. This takes place thru chemical means and is common to all soils. Very sandy soils can absorb only a small amount of ammonia; loam and clay soils are able to absorb much larger quantities, due mainly to the clay content of these soils. Therefore, when sulphate of ammonia is applied to the soil at least a part of the ammonia is absorbed by this clay present and fixed in a form which is not readily washed out. This ammonia must be changed, thru the agency of the nitrifying bacteria of the soil, to the nitrate form. Then it gradually becomes available to the plant and, of course, is then subject to leaching. These facts account for the smaller loss of nitrogen as noted in the table, from the soil receiving sulphate of ammonia as compared with that receiving nitrate of soda.

It should be remembered that the three sources of ammonia here discussed were used side by side, in the same equivalent amounts, on the same type of soil and under identical conditions so far as these could be brought about in the experimental work.

Accordingly, the behavior of each of these materials in the soil as compared with the others may be taken as strictly comparative not only in this experiment but under all usual conditions where they are used. The actual amount of each which might be lost in the drainage on different types of soil and under varied conditions would in all probability differ more or less from the results given in the table. However, the fact that nitrate of soda for instance, leaches thru to a much larger extent than sulphate of ammonia, would hold true under all ordinary conditions. The important facts brought to light in the experimental work here described regarding these nitrogenous materials and which have a practical application in grove fertilization are as follows: Nitrogen, the most expensive ingredient of fertilizers under normal conditions and usually the element most deficient in Florida soils, is the element which is lost in the largest amounts by leaching.

TABLE 5.—LOSS OF POTASH BY LEACHING

		Tank 1			Tank 3			Tank 4		
Water sampled	Grams K2O added	K2O lost	K2O in soil	Percent K2O lost	K2O lost	K2O in soil	Percent K2O lost	K2O lost	K2O in soil	Percent K2O lost
July 13	108.86	.10	108.76	.09	.30	108.56	.27	.40	108.46	.37
Aug. 23	....	.10	108.66	.09	.70	107.86	.64	.50	107.96	.46
Sept. 5	....	.70	107.96	.64	1.20	106.66	1.11	.80	107.16	.74
Nov. 22	72.57	1.30	179.23	1.20	2.30	176.93	2.15	.80	178.93	.74
Jan. 8	....	2.40	176.83	1.34	4.20	172.73	2.37	1.10	177.83	.61
Mar. 12	54.43	3.50	173.33	1.98	3.90	168.83	2.26	2.20	175.63	1.24
April 13	....	2.90	224.86	1.67	4.10	219.16	2.43	2.00	228.06	1.14
June 10	54.43	9.60	215.26	4.27	8.40	210.76	3.83	5.40	222.66	2.37
July 16	....	11.80	257.89	5.48	4.30	260.89	2.04	3.90	273.19	1.75
Aug. 23	....	10.80	247.09	4.19	....	260.89	....	....	273.19	....
Oct. 21	72.57	11.10	308.56	4.49	12.20	321.26	4.68	5.10	340.66	1.86
April 1	54.43	7.10	355.89	2.30	6.80	368.89	2.11	6.60	388.49	1.94
July 14	54.43	6.50	349.39	1.83	6.60	362.29	1.79	6.90	381.59	1.77
Aug. 9	....		403.82		....	416.72	....	....	436.02	....
Oct. 31	72.57	10.10	466.29	2.50	17.00	472.29	4.08	3.20	505.39	.73
Jan. 3	....	16.00	450.29	3.43	22.50	449.79	4.76	6.70	498.69	1.32
Jan. 24	....	7.50	442.79	1.66	14.70	435.09	3.27	10.90	487.79	2.18
Feb. 11		7.00	435.79	1.58	11.20	423.89	2.57	13.60	474.19	2.79
Mar. 6	54.43	8.30	481.92	1.90	10.20	468.12	2.41	10.20	518.42	2.15
Aug. 8	54.43	13.40	522.95	2.78	11.20	511.35	2.39	5.50	567.35	1.06
Oct. 10		19.80	503.15	3.79	6.20	505.15	1.21		567.35	
Oct. 23	72.57		503.15			505.15		3.90	563.45	.69
Dec. 21		14.60	561.12	2.90	13.40	564.32	2.65	10.30	625.72	1.83
Jan. 6		12.40	548.72	2.21	11.40	552.92	2.02	8.40	617.32	1.34
Jan. 25		13.40	535.32	2.44	11.80	541.12	2.13	8.10	609.22	1.31
April 5	54.43	16.50	518.82	3.08	13.90	527.22	2.57	12.00	597.22	1.97
May 17		9.60	573.25	1.85		581.65			651.65	

The various sources of nitrogen differ greatly in their tendency to leach out of the soil, much more of the nitrogen of nitrate of soda than of sulphate of ammonia being lost in this way.

The greatest losses take place when heavy rains occur soon after an application of nitrogenous fertilizers.

These losses decrease to a great extent as the trees become older and more of the soil becomes permeated with tree roots.

LOSS OF POTASH

Table 5 shows that a considerable loss of potash has taken place. The figures in the potash column represent the average losses for three soil tanks. The losses for the first two years are small, after which they increase considerably. This would indicate that during the first period part of the potash applied was absorbed by the soil, but that after the second year the soil had reached its maximum capacity for holding the potash and became saturated, so to speak, so that succeeding applications were not absorbed to any extent.

It is well known that practically all soils have some power to retain soluble potash. Sandy soils exhibit this capacity in the least degree, while heavy clay soils will absorb large amounts. The power of a soil to fix or absorb potash depends largely upon the presence of certain silicates which are associated with the clay present. When absorbed by the soil, water-soluble potash assumes a form which is not easily leached out by water but which is still generally regarded as being more available to plants than the potash combinations originally present. Since Florida soils as a general rule contain very little clay their power to absorb potash is limited. In the work here described it was found that at the end of four years about 30 percent of the potash applied had leached out, the remaining 70 percent being used by the trees or absorbed by the soil. In bearing groves the loss by leaching would undoubtedly be under rather than over the 30 percent found here.

LOSS OF PHOSPHORIC ACID

No table is included to show the loss of phosphoric acid since this loss has been extremely small. At the end of four years it was found that only .05 of one percent of the amount applied was lost in the drainage water. This indicates that the soil is able to absorb large amounts of soluble phosphoric acid. That this is true is shown by the fact that the soil used contained 50 percent more phosphoric acid at the end of five years than it did at the beginning of the experiment.

TABLE 6.—INCREASE IN PHOSPHORIC ACID CONTENT OF SOIL

Plot	Source of Phosphoric Acid	P2O5 in Plot	P2O5 in Check	Increase in Total	Increase in Acid-Soluble
1	Acid phosphate	2859	2633	226	200
2	Acid phosphate	3601	3002	599	480
3	Acid phosphate	4532	3449	1083	850
4	Acid phosphate	4750	3037	1713	1660
5	Acid phosphate	3701	3037	664	750
6	Acid phosphate	4080	3449	631	720
7	Acid phosphate	3513	3002	511	450
8	Acid phosphate	3082	2633	449	300
9	Acid phosphate	3720	3238	482	320
10	Acid phosphate	3213	2895	318	310
11	Acid phosphate	3783	3356	427	390
12	Acid phosphate	3357	3177	180	380
13	Acid phosphate	3916	3177	739	630
14	Acid phosphate	3659	3356	303	440
15	Acid phosphate	3396	2895	501	530
16	Acid phosphate	4372	3469	903	600
17	Acid phosphate	4286	3794	492	290
18	Acid phosphate	3861	3554	307	280
19	Acid phosphate	3598	2959	639	450
20	Acid phosphate	3472	2839	633	310
21	Acid phosphate	3456	2839	617	410
22	Acid phosphate	3516	2959	557	630
23	Acid phosphate	4210	3554	656	370
24	Dis. bone black	4115	3794	321	430
25	Steamed bone	3609	3098	511	230
26	Steamed bone	4524	3651	873	510
27	Basic slag	3643	3033	610	340
28	Basic slag	3901	3236	665	630
29	Acid phosphate	3559	3236	323	340
30	Acid phosphate	3434	3037	397	400
31	Acid phosphate	4145	3651	494	440
32	Dis. bone black	3530	3098	432	450
33	Floats	3197	2904	293	330
34	Floats	4095	3191	904	650
35	Floats	4091	3035	1056	1010
36	Floats	4466	2795	1671	1400
37	Acid phosphate	3270	2795	475	420
38	Acid phosphate	3877	3035	842	540
39	Acid phosphate	3507	3191	316	420
40	Acid phosphate	3529	2904	625	510
41	Acid phosphate	3432	2997	435	300
42	Acid phosphate	3510	2820	690	520
43	No fertilizer	3348	3348	0	—30
44	Acid phosphate	3815	3142	673	380
45	Acid phosphate	3735	3142	593	490
46	Acid phosphate	3716	3348	368	320
47	Acid phosphate	3192	2860	332	400
48	Acid phosphate	3529	2997	532	460

PHOSPHORIC ACID

In studying the effect of the fertilizers used on the composition of the soil, especial attention was given to the phosphoric acid. Work at the Experiment Station with soil tanks has shown that the loss of phosphoric acid in the drainage water where acid

phosphate was used was so small as to be negligible, and that practically all the phosphoric acid applied was retained by the soil. The work with the grove soils has confirmed these results. Samples of soil from the fertilized plots and from the middle of the tree rows were taken from time to time to a depth of 9 inches, and determinations made of the phosphoric acid. Work elsewhere has shown that the greater part of the phosphoric acid absorbed by soils is retained in the upper plowed soil, so in this work sampling to a depth of 9 inches was considered sufficient. The difference between the amount of phosphoric acid in the soil of the plot and that in the corresponding middle would show the quantity fixed by the soil. These results for the different plots are given in Table 6. In order to make the results easily comparable they have been calculated to pounds per acre. The figures in the table represent in every instance the average of the results obtained from three different samplings of soil, the third being taken in July, 1915. The second column from the right shows the increase in phosphoric acid content, due to the absorption by the soil of the phosphate fertilizer applied. It will be noted that these figures vary considerably among themselves, even where the amount and form of phosphoric acid applied has been identical. This variation can be accounted for by the difficulty of obtaining samples of soil which are perfectly representative of the plots. However, it will be noted that those plots receiving the largest applications of fertilizer also show the greatest amounts of phosphoric acid retained. Plot 4, receiving four times the standard quantity of fertilizer shows the greatest fixation, an increase of 1713 pounds per acre being noted. The source of the phosphoric acid on this plot was acid phosphate. Plot 36 receiving the same amount of actual phosphoric acid as plot 4, but in the form of floats, shows a gain practically the same as plot 4. Both these plots show an increase of over 50 percent. Altho five different sources of phosphoric acid were used on the plots, the form in which it was used does not appear to have had any influence on the power of the soil to absorb this material, the water-soluble form being retained as thoroly as the insoluble forms.

CHANGES OF PHOSPHORIC ACID IN SOIL

It is believed that the figures in the last column of Table 6 throw some light on the question as to what forms the phosphoric acid assume after being incorporated with the soil. It is generally agreed upon among soil investigators that the phos-

phoric acid of the soil exists mainly in three forms, namely, the phosphates of lime, iron, and alumina. It is generally considered that the last two forms are much less available to plants than the first form. Indeed it is held by many that the phosphates of iron and alumina are but very slightly available because of their practical insolubility in the soil water. Phosphate of lime, on the other hand, dissolves slowly in the soil water containing carbonic acid gas and other weak acids and is thus considered more available to plants. The fixation of soluble phosphoric acid in the soil is explained by the fact that it combines with one or more of the compounds of iron, aluminum or lime present and thus assumes an insoluble form. It then becomes a matter of some practical importance to know whether the phosphoric acid added to the soil assumes the form of the insoluble iron and aluminum phosphates or the more readily available phosphate of lime. A method of treatment which it is believed will distinguish between the different forms has been developed by soil chemists and has been used to some extent. It depends upon digesting the soil in a weak solution of nitric acid, which will dissolve the phosphate of lime present but which has no effect upon the phosphate of iron and alumina. A given weight of soil was treated with fifth-normal nitric acid (about 1.26 percent acid) and the amount of phosphoric acid dissolved out determined, this dissolved phosphoric acid being regarded as coming entirely from the phosphate of lime present. The soil samples used were those on which the total phosphoric acid had been determined as shown in the table. The results given in the table represent the difference between the amounts dissolved from the plot soils and those of the corresponding middles, thus representing the increase in the acid soluble phosphoric acid of the fertilized plots, and are calculated to pounds per acre.

Some interesting facts are brought out by comparing these results with the figures representing the increase in total phosphoric acid. Those plots showing the greatest increase in total phosphoric acid also show the greatest increase in acid-soluble. Plot 4 again shows the greatest increase, followed by plot 36. The average increase in acid-soluble phosphoric acid for all the plots (omitting plot 43) is 494 pounds, as compared with an average increase in total of 586 pounds. Assuming that the acid used dissolved out only phosphate of lime and no iron or aluminum phosphate, these figures indicate that about 80 percent of the increase in phosphoric acid content in the plots has been fixed in the form of phosphate of lime.

TABLE 7.—NITROGEN CONTENT OF PLOT SOILS

Plot	Nitrogen in Plot	Nitrogen in Middle	Plot	Nitrogen in Plot	Nitrogen in Middle
1	1140	780	25	1350	1020
2	1170	990	26	1080	930
3	1080	1050	27	1110	1080
4	810	1140	28	1140	1140
5	870	1140	29	1290	1140
6	1170	1050	30	1020	1080
7	1140	990	31	1230	930
8	1140	780	32	1440	1020
9	1080	840	33	1200	1050
10	990	1110	34	1140	1050
11	1170	990	35	1170	1140
12	1140	1020	36	1230	1050
13	1410	1020	37	1320	1050
14	1440	990	38	1410	1140
15	1410	1110	39	1080	1050
16	1230	840	40	1110	1050
17	1170	960	41	1230	810
18	1260	1080	42	1380	1140
19	1260	1080	43	900	990
20	1230	990	44	1230	1290
21	1320	990	45	1920	1290
22	1350	1080	46	720	990
23	1260	1080	47	780	1140
24	1440	960	48	720	810

NITROGEN

Table 7 gives the amount of nitrogen in pounds per acre to a depth of 9 inches. The soil samples were taken from the plots and from the middles at the end of the experiment in 1918. One fact brought out here is the considerably smaller amount of nitrogen in the clean culture plots, 46, 47 and 48, as compared with the remaining forty-five plots. The average amount of nitrogen in these three plots is 740 pounds per acre, as compared with an average for the others of 1220 pounds an acre, indicating a loss of 480 pounds or 39 percent. This loss must be attributed largely to the effects of the continuous cultivation. This practice leads to more rapid nitrification of the organic nitrogen of the soil, changing the insoluble nitrogen to the soluble nitrate form which is easily leached out. This loss of organic matter also means a decrease in the capacity of the soil for holding moisture and soluble fertilizers added to it.

The average of the forty-eight soils taken from the middles is 1030 pounds of nitrogen per acre. It is interesting to compare this figure with the average of fifteen samplings taken at the beginning of the experiment in 1909. These samples were taken at various places over the field and probably give a fair average of the nitrogen content at that time. The amount of nitrogen

found in this way was 1080 pounds per acre. This is so close to the average for the middles (1030 pounds) at the end of the experiment that it is reasonable to assume that the unfertilized soil between the tree rows neither gained nor lost in nitrogen during the ten years. In other words, the loss of nitrogen thru leaching was counterbalanced by the addition of nitrogen by means of the leguminous cover crop. The fertilized plots have gained slightly in nitrogen as compared with the soils from the middle of the rows. Omitting the clean culture plots and the no fertilizer plot, the average is 1220 pounds per acre, a gain over the middles of 190 pounds.

TABLE 8.—POTASH CONTENT OF PLOT SOILS AT END OF EXPERIMENT IN 1918

Plot	Potash	Plot	Potash
1	1620	25	2160
2	1800	26	1530
3	2010	27	2070
4	2040	28	1950
5	1740	29	1620
6	1830	30	2040
7	1740	31	1950
8	1740	32	2040
9	1830	33	1440
10	1530	34	1950
11	1740	35	1530
12	1950	36	1830
13	1830	37	1830
14	1950	38	2160
15	1620	39	1440
16	1740	40	1680
17	1530	41	1950
18	1740	42	1830
19	2160	43	1140
20	1950	44	1830
21	2250	45	1620
22	1950	46	1620
23	1440	47	1440
24	2040	48	1530
Unfertilized soil 1140			

POTASH IN GROVE SOIL

The amount of potash present in the different plots at the end of the experiment in 1918 is given in Table 8. The results are calculated in pounds per acre to a depth of 9 inches, and represent the total amount of potash in the soil to that depth. The unfertilized middles were also sampled, and potash determined in seven of these soils. The average of these seven soils amounts to 1140 pounds per acre. By comparing this figure with those for the various plots, the increase in the latter due to the potash in the fertilizer may be determined. It will be noted that

TABLE 9.—GAIN IN DIAMETER OF TREES FOR 10 YEARS

Plot	Gain	Fertilizer Treatment
2	139	Standard.
1	138	One-half standard.
12	136	Standard and air-slaked lime.
13	134	Standard. Mulched.
47	133	Nitrogen from dried blood. Clean culture.
46	132	Standard. Clean culture.
16	130	Nitrogen, ½ nitrate of soda, ½ sulphate of ammonia.
45	130	Standard. Mulched.
31	128	Standard.
48	127	Nitrogen from nitrate of soda. Clean culture.
37	127	Potash from low-grade sulphate.
25	127	Phosphoric acid from steamed bone.
22	126	Nitrogen, ½ cottonseed meal, ½ sulphate of ammonia.
8	125	Phosphoric acid and potash decreased by one-half.
30	124	Acid phosphate, nitrate of soda, hardwood ashes.
41	124	Standard.
6	123	Phosphoric acid and potash increased by one-half.
36	123	Phosphoric acid from floats. (4 times amt.) Cottonseed meal.
35	122	Phosphoric acid from floats. (4 times amt.)
9	121	Phosphoric acid and nitrogen decreased by one-half.
38	120	Potash from muriate.
44	118	Standard.
21	114	Nitrogen from cottonseed meal. Ground limestone.
23	114	Nitrogen, ½ cottonseed meal, ½ nitrate of soda.
3	114	Twice standard.
20	113	Nitrogen from cottonseed meal.
26	112	Phosphoric acid from steamed bone. (2 times amt.)
32	112	Phosphoric acid from dissolved bone black.
34	111	Phosphoric acid from floats. (2 times amt.)
42	111	Potash from nitrate of potash. Balance nitrogen, nitrate of soda.
19	110	Nitrogen, ½ nitrate of soda, ½ dried blood.
11	110	Standard and ground limestone.
24	110	Phosphoric acid from dissolved bone black.
15	109	Nitrogen from nitrate of soda.
27	109	Phosphoric acid from Thomas slag. Nitrate of soda.
7	108	Nitrogen and potash increased by one-half.
33	107	Phosphoric acid from floats.
18	106	Nitrogen, ½ sulphate of ammonia, ½ dried blood.
29	105	7½ percent potash in June, 7½ in October, 3 in February.
40	104	Potash from kainit.
14	103	Standard.
10	102	Nitrogen and potash decreased by one-half.
43	101	No fertilizer.
28	96	Phosphoric acid from Thomas slag. (2 times amt.) Nitrate of soda.
17	90	Nitrogen from dried blood.
39	88	Standard. Ground limestone.
5	75	Phosphoric acid and nitrogen increased by one-half.
4	65	Four times standard.

all the fertilized plots show an increase over the unfertilized soil, thus indicating that this soil was able to retain at least a portion of the soluble potash applied. The average increase for the forty-seven plots amounts to 660 pounds per acre, or an increase of over 50 percent for the ten years of the experiment.

A large proportion of the potash in the plot soils is held in

a very insoluble form, probably largely as feldspar. Treatment of these soils with strong hydrochloric acid dissolved on the average only 15 percent of the total potash present.

TABLE 10.—RANK OF PLOTS

Rank	1910	1911	1912	1913	1914	1915	1916	1917	1918
1	46	46	46	47	2	2	2	2	2
2	30	47	47	46	1	47	1	1	1
3	45	35	35	36	47	1	46	47	12
4	41	41	41	37	46	13	13	48	13
5	29	44	48	13	13	12	12	12	47
6	24	36	2	41	36	48	47	13	46
7	26	48	36	48	41	36	48	25	16
8	5	37	37	12	12	37	45	46	45
9	13	43	22	22	37	46	25	8	31
10	35	16	44	2	45	22	37	31	48
11	31	22	30	35	48	30	22	37	37
12	22	2	43	30	22	41	36	9	25
13	23	8	42	31	30	25	30	36	22
14	43	42	12	45	44	35	31	11	8
15	47	6	13	38	21	31	41	35	30
16	19	30	1	44	38	21	8	6	41
17	36	45	38	34	43	44	35	22	6
18	42	26	20	8	35	38	11	30	36
19	17	25	31	26	8	45	9	44	35
20	30	38	8	43	9	11	6	45	9
21	21	12	16	21	29	6	16	16	38
22	49	11	34	29	31	43	21	20	44
23	37	19	26	25	23	9	26	24	21
24	14	34	6	23	16	29	29	23	23
25	15	31	29	42	32	23	38	32	3
26	8	33	33	20	42	8	32	29	20
27	27	39	23	32	25	16	23	26	26
28	44	20	11	6	24	32	44	21	32
29	32	24	32	28	20	34	20	38	34
30	34	29	19	1	11	26	24	42	42
31	6	1	45	33	6	24	3	3	19
32	38	7	25	9	39	15	34	19	11
33	35	13	7	11	34	20	19	15	24
34	4	27	21	39	33	42	43	10	15
35	3	9	39	24	26	28	28	14	27
36	25	32	9	19	15	10	42	34	7
37	16	14	24	7	7	3	15	27	33
38	10	23	14	3	3	33	27	33	18
39	18	21	27	10	19	39	33	43	29
40	40	3	3	15	10	19	7	18	40
41	11	5	28	18	14	27	10	7	14
42	21	28	10	14	40	7	14	40	10
43	9	17	40	27	17	14	18	41	43
44	12	10	15	40	27	40	40	28	28
45	28	40	17	16	18	18	39	17	17
46	2	15	5	5	28	5	17	39	39
47	1	18	18	17	5	17	5	5	5
48	7	4	4	4	4	4	4	4	4

EFFECT OF FERTILIZERS ON GROWTH

The effect of the various fertilizer treatments used in producing growth was measured each year by taking the diameter of the tree trunks. Table 9 gives the average measurements of

the trees in the various plots at the end of the experiment. The measurements are given in thirty-seconds of an inch. These figures were obtained by subtracting the original diameter of the tree when set out from the final measurement at the end of 1918. In each case they are the average of the ten trees in each plot, and give the actual increase made by the trees. Similar measurements were taken every year during the continuation of the experiment. The standing of the different plots from year to year, beginning with 1910 is shown in Table 10.

In Table 9 the plots are arranged in the order of the increase in growth made at the end of the ten years, the plot making the largest increase being placed at the head of the list. This table brings out the fact that in this experiment a number of sources of materials have proven almost equally valuable in producing growth and that several have had an injurious effect. Among the fertilizers used on the plots making the most growth no single source has shown any remarkable superiority over others used, altho there is a considerable variation in the effect of the different materials. The results of this work emphasize the fact that the citrus grower need not be restricted in his choice of fertilizers to one particular material, but that there are a number of sources of the three essential elements which can be used to advantage. It should be stated that the soil on which this experiment was located was somewhat above the average in fertility, especially in phosphoric acid content. This fact has served to minimize differences which might otherwise have developed between the fertilizers used and especially the sources of phosphoric acid. The behavior of plot 43, which received no fertilizer during the time the experiment continued brings out the fact that the soil was unusually well supplied with plant food. However, a study of the table brings out the fact that the plots making the best growth have received the standard mixture of sulphate of ammonia, acid phosphate and high grade sulphate of potash. Of the best 16 plots, all but one have received acid phosphate as the source of phosphoric acid. The one exception is plot number 25, receiving steamed bone and ranking twelfth in the list. All but two plots in these sixteen have received high grade sulphate of potash as the source of potash. The two exceptions are plot number 37 receiving low grade sulphate of potash and plot number 30 receiving hard wood ashes, and ranking eleventh and fifteenth, respectively. Of the five different sources of nitrogen used, all are represented in the best 10 plots. Sulphate of am-

monia, nitrate of soda, and the nitrogen of steamed bone have all produced good growth. It will be noted that plot number 2, receiving the standard mixture, stands at the head of the list. As stated elsewhere, this standard mixture consisted of sulphate of ammonia, acid phosphate, and high grade sulphate of potash. This mixture was applied at the rate of 2 pounds per tree three times per year. The amount was increased as the trees increased in size, the application finally being at the rate of 6 pounds three times per year.

Plot number 1, receiving one-half the standard amount, or at the beginning 1 pound per tree three times per year, shows practically the same increase in growth as plot 2. Plot number 3, receiving twice the standard amount, or 4 pounds per tree at the beginning ranks twenty-fifth, while plot number 4, receiving four times the standard amount or 8 pounds per tree, ranks at the foot, having made less growth than any of the plots. The standing of this series of four plots brings out the fact that in this experiment plot number 1 was receiving about the optimum amount of fertilizer which it would pay to apply to trees of this age, and that plot number 2 received the maximum amount which could be applied without inducing injury. The fact that plots 2 and 1 made practically the same amount of growth indicates that the former was receiving more fertilizer than the trees could profitably use, altho not enough to injure them in any way. The appearance of these two plots was very similar, the eye not being able to detect any difference in size, character of growth, or appearance of the leaves. Plot number 3, receiving twice the standard amount of fertilizer has developed considerable injury. This injury was shown soon after the beginning of the experiment, was quite severe for several years, but finally became much less apparent. This would indicate that 4 pounds per tree three times per year was about the maximum amount of fertilizer which could be applied to young trees and not kill them outright. The injury was severe during the first few years but the trees managed to survive and finally to overcome the injurious effects. The behavior of this plot in thus overcoming the injurious effects of too much fertilizer is shown in Table 10. It will be noted that in 1911 and 1912 this plot ranked number forty in the list. In 1913 and 1914 it rose to thirty-eighth; in 1915 to thirty-seventh; in 1916 and 1917 to thirty-first; and in 1918 to twenty-fifth. This rise in rank indicates that as the trees became older they were better able to withstand the effects pro-

duced by too much fertilizer. The early injury, however, resulted in a permanent stunting of the trees. At the end of the experiment they were about three-fourths as large as the trees of plots 1 and 2.

Plot 4 shows the maximum injury from the use of too much fertilizer. These trees were stunted from the beginning and have made very little growth. By the winter of 1912 half of the trees in this plot were dead and had to be replaced by others. In the spring of 1913 the excessive applications were discontinued and from that time on only one pound per tree was used three times per year. The new trees used to replace those killed by the fertilizer have failed to make much growth. At the end of the experiment this plot was less than one-fourth the size of plots 1 and 2 and consisted of almost worthless trees which will probably never amount to much. Photographs of plots 2, 3 and 4 are reproduced in Fig. 4.

The behavior of plots number 5, 6 and 7 is interesting in this connection, because of its bearing on the question as to which of the fertilizing elements used was chiefly responsible for the injury produced. In this series of three plots two of the elements were increased by one-half, the third being used in the standard amount. In the mixture applied to plot 6 the acid phosphate and high grade sulphate of potash used was one and one-half times the amount used in the standard mixture, the sulphate of ammonia remaining the same as in the latter. Plot 7 received 1½ times the nitrogen and potash of the standard and plot 5 received 1½ times the nitrogen and phosphoric acid of the standard. It will be noted that the least amount of growth was made by plot 5 which ranks forty-seventh in the list. This plot showed all the signs of severe injury caused by too much fertilizer. In the table showing the rank of the plots by years plot 5 stood forty-first in 1911 and dropped still lower from year to year, until for the last three years it stood next to the lowest.

Plot 7, where the nitrogen and potash were increased, has made a better growth than plot 5 but not as much as plot 6. The latter plot shows no injury from the increased phosphoric acid and potash used. The trees in plot 7 show some injury caused by too much fertilizer but the injury is not quite so marked as in plot 5. The behavior of these three plots brings out the fact that excessive quantities of nitrogen are much more injurious than similar quantities of phosphoric acid and potatsh and that increased ratios of nitrogen and potash are less inju-

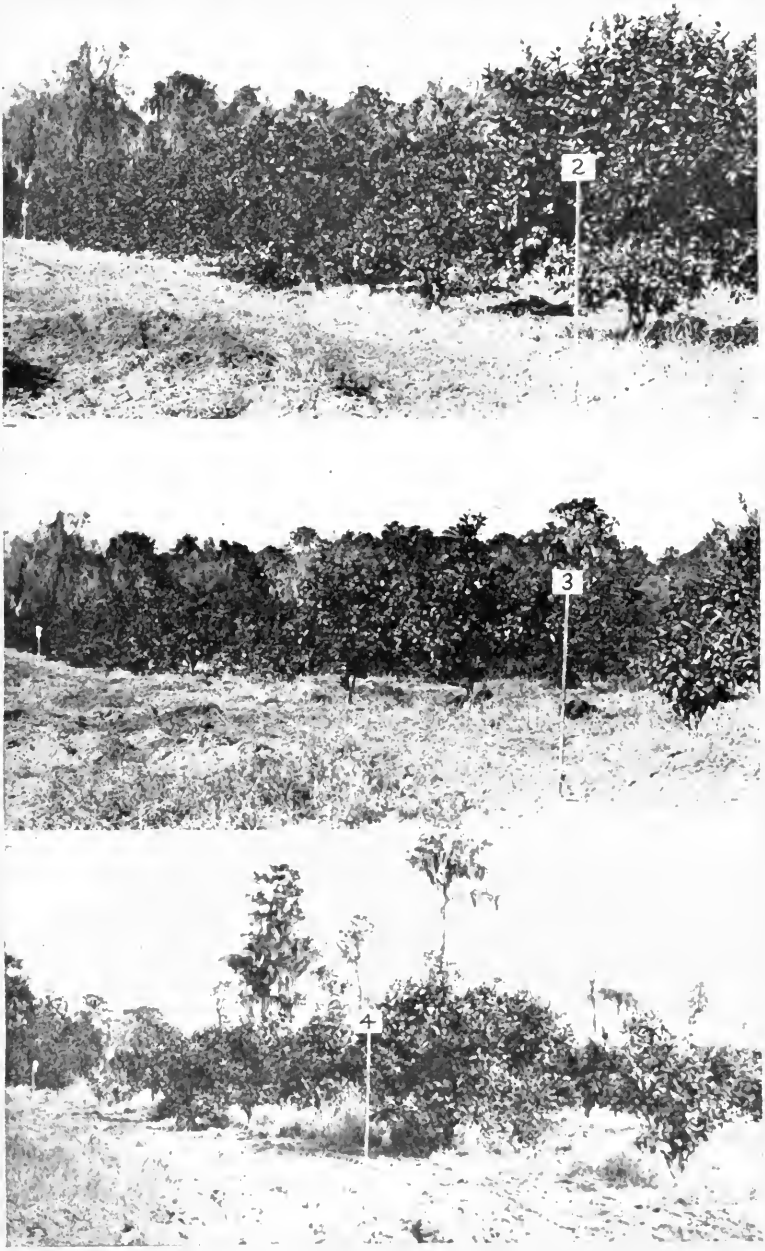

Fig. 4.—Plots 2, 3 and 4 show the effect on the orange trees when too much fertilizer is used

Plot 2 was fertilized with the standard mixture. Plot 3 received twice this amount and, from the smaller size of the trees shows that some injury was caused. Plot 4 received four times the standard mixture and consists largely of new trees, the original trees being practically killed by the excessive quantities of fertilizer used. Plot 2 is the best plot of the forty-eight; plot 3 ranked twenty-fifth, and plot 4 forty-eighth.

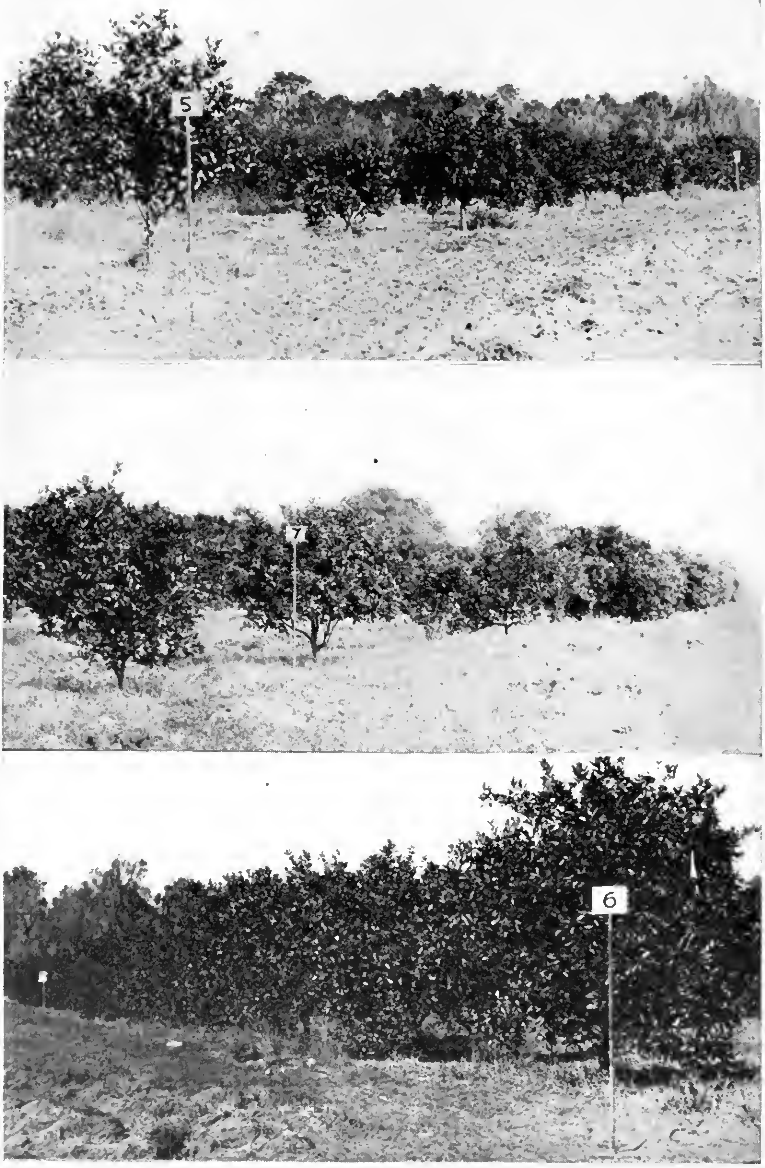

Fig. 5.—Results of plots when two elements in the standard mixture were increased.

rious than similar increases of nitrogen and phosphoric acid. See Fig. 5 for photographs of these plots.

The mulched plots and the plots which received clean cultivation the entire year are among the best in the grove. This treatment has been of benefit in two ways: by conserving moisture and supplying additional nitrogen. The cultivation thru the year has led to increased nitrification of the organic matter of the soil thus liberating a supply of available nitrogen in addition to that supplied in the fertilizer. Determinations on several occasions during the early years of the experiment have shown that these plots contained more nitrates in the soil than was found in the soil of adjacent plots. The soil on which the plots were located was naturally a rather dry soil so that the continuous cultivation and the mulch of dry leaves and weeds have aided in conserving moisture during dry periods. Table 10 shows that the clean culture plots made more growth than any others during the early years of the experiment but that after 1913 they did not do quite so well. This would indicate that for young trees continuous clean cultivation is of benefit in promoting good vigorous growth, but after a few years it is possible to cultivate too much. Determinations made at the end of the experiment show that the soil of the clean culture plots has lost about 18 percent of the organic matter due to the continuous cultivation as compared with the soil of adjacent plots. (See Fig. 6 for photograph of plot 46.)

SOURCES OF NITROGEN

Sulphate of ammonia and nitrate of soda are the most commonly used sources of nitrogen for citrus trees. They are usually the least expensive per pound of nitrogen and as a rule have given the best results in practice. It has been pointed out elsewhere that the continued use of sulphate of ammonia increases the acidity of the soil while nitrate of soda decreases acidity, and this opposite tendency of the two materials has been presented as an argument for using them together or alternating one with the other. Additional important reasons for thus using them can be given. In the discussion on soil tanks it was pointed out that the loss of nitrate of soda by leaching was much greater than sulphate of ammonia, and that the losses were greatest after heavy rains. In order to get the maximum benefit from the use of nitrate of soda it should be used in small applications during the drier season of the year. Its nitrogen being

Fig. 6.—Plot 43, no fertilizer; Plot 32, dissolved bone black; Plot 46, standard and clean culture

Plot 43 received no fertilizer during the period of the experiment. It ranks forty-third. On plot 32 dissolved bone black was used instead of acid phosphate. This plot ranked twenty-eighth. Plot 46 was fertilized with the standard mixture, and in addition was cultivated thru the entire year. It ranked sixth at the end of the experiment.

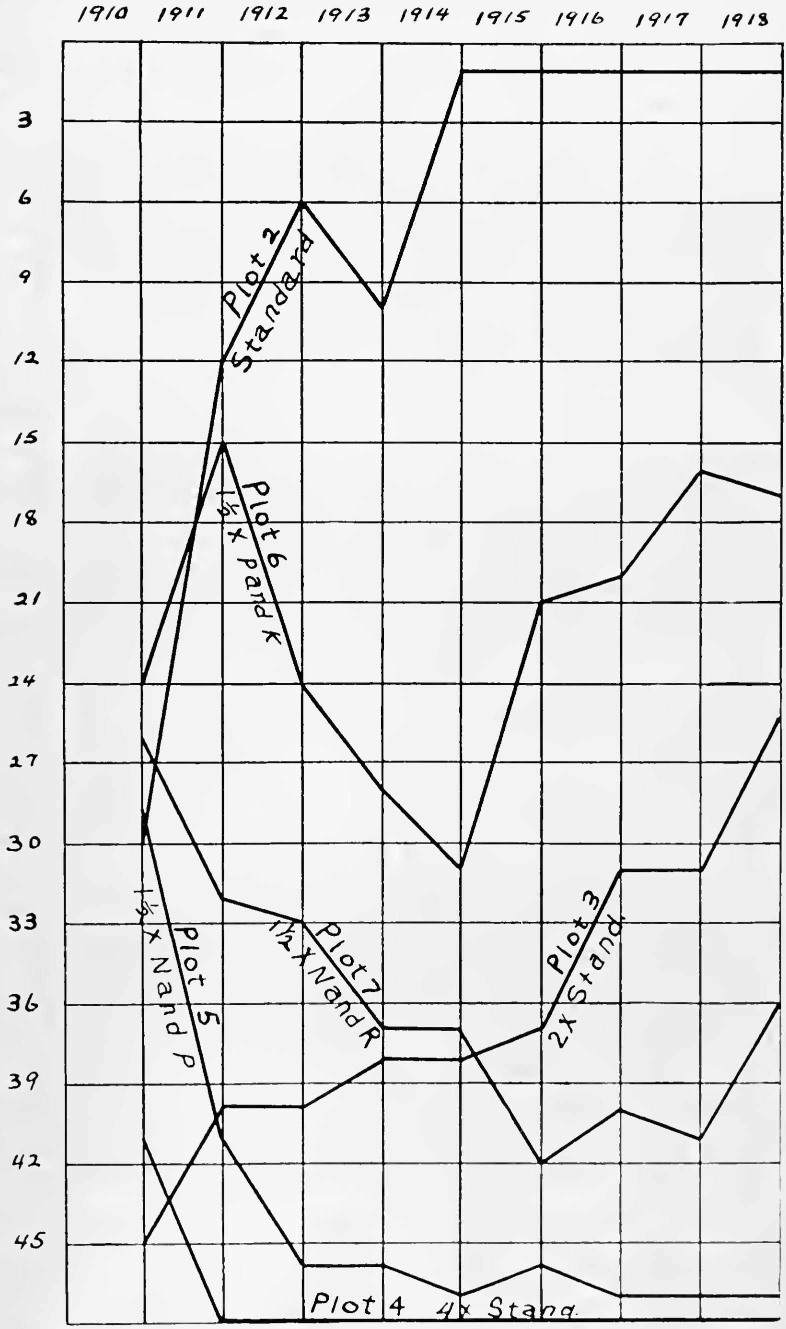

Fig. 7.—This figure shows effects of excessive amounts of fertilizer

immediately available to the tree it is an excellent material to use in the spring application of fertilizers. At this time the tree is preparing to put out the spring growth and produce bloom and more nitrogen is needed at this time than during any other period of the year. Nitrate of soda supplies this need in a form which the trees can use as soon as it is placed in the soil. Later on in the season if the trees have a yellow color and show lack of nitrogen a light top dressing of nitrate of soda will usually be of considerable benefit, not only in putting the trees into healthy growing condition but in assisting in the development of the fruit. The only disadvantage likely to occur in using nitrate of soda in this way comes when it is applied to a very dry soil. It may remain unused in the soil for some time, until a rain occurs, making it at once available, and the trees absorb so much of it that injury results. This is not likely to happen if small amounts are used. From 2 to 3 pounds of nitrate of soda to trees bearing ten boxes of fruit may be considered a rather light application.

Sulphate of ammonia may be expected to be of greater benefit during the wet season. It has been shown that this material is much less liable to be leached out of the soil than nitrate of soda. Therefore, during the rainy season its effects will be more lasting and extend over a longer period than nitrate of soda. In other words, it will furnish a more constant and uniform supply of nitrogen during the wet period. The ammonia of this material becomes available to the plant only after it has been changed to the nitrate form thru the process of nitrification. This change is brought about gradually and thus the effects of the sulphate of ammonia are extended over a longer period. It will be noted in Table 9 that plot 16 which received one-half of the nitrogen in the form of sulphate of ammonia and the other half as nitrate of soda made a better growth than any plot receiving nitrate of soda exclusively, thus emphasizing the point brought out that the two materials used together will give better results than where nitrate of soda is used alone.

ORGANIC SOURCES OF NITROGEN

Two plots, 25 and 26, received steamed bone as the source of phosphoric acid and as this material carried a little over 3 percent ammonia this was taken into account. As the quantity of steamed bone required to supply the proper amount of phosphoric acid furnished less than one-fourth enough nitrogen the balance was made up of sulphate of ammonia, so that the main

source of nitrogen for these trees was the latter material. The behavior of steamed bone as a source of phosphoric acid is discussed in the section on Sources of Phosphoric Acid.

With one or two exceptions the plots receiving dried blood or cottonseed meal are not among the best. Plot 47, one of the best in the experiment, received clean cultivation in connection with dried blood, during the entire period. It has already been pointed out that this cultivation was of marked benefit in producing growth, especially during the early years of the experiment. On plot 22 cottonseed meal was used in connection with sulphate of ammonia, the amount of the latter being the same as was used on plot 1 which ranked second in the series. While these materials have not brought about any actual injury and, contrary to the general opinion, have not produced dieback, this experiment has shown that they should not be relied upon as the sole source of nitrogen for citrus trees. Experience has shown that an occasional application of one or the other may be of benefit probably in stimulating the growth of the beneficial soil bacteria, but when used continuously they are distinctly inferior to the mineral sources of nitrogen.

SOURCES OF PHOSPHORIC ACID

Of the five sources of phosphoric acid used, acid phosphate has given the best results. The eleven best plots all received this material. Steamed bone has also given good results, plot 25, which received this material, ranking twelfth in the list. No explanation can be given for the poor behavior of dissolved bone black in this experiment. As Table 10 shows, neither of the two plots, 24 and 32, fertilized with this material, have ever ranked above twenty-third during the ten years of the experiment. The same thing may be said with regard to plots 27 and 28, fertilized with Thomas slag. These two plots have stood near the bottom of the list during the ten years' work. The trees in both these plots have shown evidence of malnutrition, such as frenching, and in some years have produced but a small amount of new growth. Plot 28, receiving twice as much Thomas slag as plot 27, consists on the average of somewhat smaller trees, showed more frenching from time to time, and in general showed more pronounced symptoms of poor nutrition during the period of the experiment than did plot 27.

USE OF FLOATS

Plots 33, 34, 35 and 36 were fertilized with finely ground raw rock phosphate, commonly known as floats. The formulas used

were as follows: Plot 33, 5-6-6, from sulphate of ammonia, floats and high grade sulphate of potash; plot 34, 5-12-6, from the same materials; plot 35, 5-24-6, from the same materials; plot 36, 5-24-6, from cottonseed meal, floats and high grade sulphate of potash.

At the end of the experiment plots 35 and 36 were receiving a quantity of floats equivalent to a yearly application of over 1300 pounds per acre. It will be noted that these two plots made the best growth among the float plots. In 1912 they ranked third and seventh respectively. From 1913 on they gradually declined as compared with other plots, until at the end of the experiment in 1918 they were in the nineteenth and eighteenth places. Plot 36 made somewhat more growth on the average than plot 35. The rank of plot 36 from year to year is shown graphically in Fig. 8. It will be noted that plot 36 was at its best in 1913, and that from that year on there was a gradual decline in comparative growth. This decline may probably be attributed to the inability of the trees to obtain sufficient phosphoric acid from the floats to make maximum growth. However, both 35 and 36 were among the best half of the plots at the end of 1918.

AVAILABILITY OF PHOSPHATES

The better results obtained by the use of acid phosphate over other sources of phosphoric acid, should in all probability be attributed to its more ready availability. A large proportion of the phosphoric acid which it carries is soluble in water, while such materials as bone, Thomas slag and floats contain no water-soluble phosphoric acid. So far as known the phosphoric acid of the soil is absorbed by the plant roots in only one form, namely, the mono-calcium phosphate, or the so-called water-soluble form found in acid phosphate. This form contains one part of lime combined with two parts of phosphoric acid. When acid phosphate is added to the soil the mono-calcium phosphate combines with more lime to form the di-calcium phosphate, or the so-called "reverted" phosphate, which contains two parts of lime combined with two parts of phosphoric acid. The reverted form is fairly soluble in water containing carbon dioxide. Usually an additional change takes place later on and the reverted form combines with still more of the lime of the soil and forms tri-calcium phosphate, containing three parts of lime combined with two of phosphoric acid. This is the form of phosphoric acid found in floats and bone.

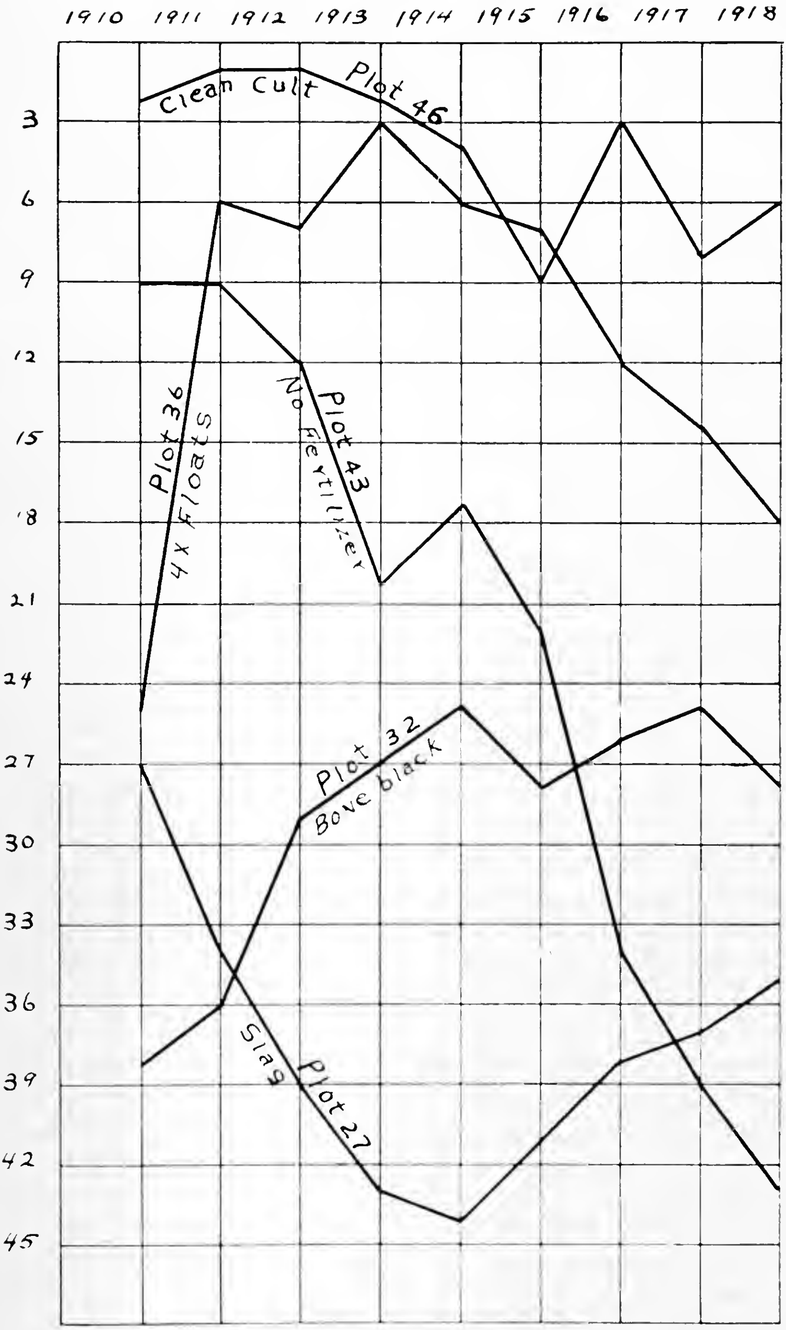

Fig. 8.—Comparative growth of plots 27, 43, 32, 36 and 46

The thought might occur that since acid phosphate after being added to the soil ultimately assumes the form of the tri-calcium phosphate, it would be reasonable to expect as good results from a direct application of the latter form of material. The difference in availability is explained by the fact that when acid phosphate is added to the soil it dissolves in the soil water and is soon distributed uniformly and widely among the soil particles. When it changes to the reverted form it remains as a thin film deposited over the surface of the particles of soil and thus is in the best possible condition to go into solution thru the action of the soil water and to come into contact with the tree roots.

Where the insoluble phosphates are used it is impossible to obtain as thoro and uniform a distribution of the solid particles of the material, even if very finely powdered, as it is in the case of a solution.

The phosphoric acid of steamed bone, altho in the form of tri-calcium phosphate, is more readily available than the same form as contained in floats. In the former material the phosphoric acid is intimately associated with the organic material of the bone. When this decays it acts on the insoluble phosphate and makes it gradually available. Steamed bone has usually given excellent results as a source both of nitrogen and of phosphoric acid, and while not as quick acting as some other materials, its effects are usually more lasting. It is usually considered that about one-half of the phosphoric acid of steamed bone becomes available the first season, the remainder gradually becoming available in succeeding years.

SOURCES OF POTASH

Of the six sources of potash used in this experiment, the high grade and low grade sulphates and hard wood ashes have all given excellent results. The best ten plots all received high grade sulphate of potash. Plot 37 to which low grade sulphate of potash was applied, ranked eleventh at the end of the work. The hard wood ashes plot ranked fifteenth. One objection to the continuous use of the latter material has been brought out in this experiment, and is discussed in the section dealing with lime and other alkaline materials. The frenched condition of the trees brought on by the ashes was not so severe as on other plots, but was sufficient to interfere somewhat with normal growth. An occasional application of ashes to citrus trees would probably

give very little if any trouble. The muriate and the nitrate of potash gave only fair results. The trees on these two plots did not produce quite the thrifty, vigorous growth characteristic of the best plots.

The trees in plot 40, which received kainit as the source of potash, made very poor growth during the entire period of the experiment. Compared with plots receiving the high and low grade sulphate and ashes, they were smaller in size, growth was less abundant, and appeared much less thrifty and vigorous. This plot received the same treatment as plot 41 in the next row, excepting the source of potash, but the trees were not more than two-thirds the size of those in plot 41.

SOIL ACIDITY

Table 11 gives the lime requirement of the various plots for four different dates, samples of soil being taken in March, July, and December of 1913 and in July, 1915. By the term "lime requirement" is meant the amount of lime necessary to be added to the soil to bring about an alkaline reaction. In the method used the soil is treated with varying quantities of lime water of standard strength until the proper amount necessary to give an alkaline reaction is reached. The figures in the table represent pounds of calcium carbonate (ground limestone) per acre. Samples of soil were taken from the plots where the fertilizers had been applied and also in the middle of the tree rows where the soil had never been fertilized. The difference between the lime requirement of any plot and the corresponding middle would show the effect of the fertilizer used on the plot in increasing or decreasing the acidity of the soil. It will be noted from the table that plots 11, 12, 21 and 39, receiving ground limestone, and plot 30, receiving hardwood ashes, all show an alkaline reaction, due to the effect of these basic materials in neutralizing the acidity originally present and also that which may have developed from time to time. Plots 27 and 28, receiving basic slag and nitrate of soda, show a marked decrease in lime requirement as compared with the corresponding checks. Basic slag has an alkaline reaction and contains usually a small excess of lime over and above that in combination with the phosphoric acid in it. This excess of lime is seldom over 5 to 10 percent. Hence, basic slag in the amounts ordinarily applied in practice would not supply sufficient lime to neutralize the acid condition of a sour soil except in a limited degree as is here shown. The

TABLE 11.—LIME REQUIREMENT. POUNDS PER ACRE, 9 INCHES

Plot No.	March, 1913		July, 1913		Dec., 1913		July, 1915	
	Plot	Middle	Plot	Middle	Plot	Middle	Plot	Middle
1	1600	1070	2140	1070	1600	1070	2140	2140
2	2670	1600	3210	2670	3210	1600	3740	2670
3	2670	1070	3210	2670	3210	2140	4810	2140
4	3210	1070	3740	2140	2670	2140	4810	1600
5	2670	1070	3740	2140	3740	2140	5350	1600
6	4280	1070	3740	2670	3740	2140	4810	2140
7	2670	1600	3740	2670	3210	1600	3740	2670
8	2670	1070	3210	1070	2140	1070	3740	2140
9	2670	1070	3210	2140	2140	1600	2670	1600
10	2670	2140	3210	2670	3210	2140	3210	3210
11	Alk.*	2670	Alk.*	3210	Alk.*	3210	Alk.*	2670
12	Alk.*	2670	Alk.*	3210	Alk.*	3210	Alk.*	4280
13	3740	2670	4280	3210	4280	3210	4810	4280
14	2670	2670	3740	3210	3740	3210	4810	2670
15	2670	2140	3740	2670	2670	2140	2670	3210
16	2670	1070	2140	2140	2670	1600	3740	1600
17	2670	2670	3210	3210	3210	2670	4810	3210
18	2670	2670	3740	4810	2670	2670	4280	2670
19	2670	2140	4280	3210	2140	2670	4280	3740
20	2670	2670	3740	4280	2670	2670	3740	3210
21	Alk.*	2670	Alk.*	4280	Alk.*	2670	Alk.*	3210
22	2670	2140	5350	3210	4280	2670	4280	3740
23	2670	2670	4810	4810	2670	2670	5350	2670
24	2670	2670	5890	3210	3740	2670	4280	3210
25	2670	2670	3740	3740	2670	2670	3210	3210
26	2140	2670	4810	2670	3210	2670	3210	2670
27	1600	2140	2140	3740	2140	2140	1600	2140
28	1070	2670	3210	3740	1070	2670	2140	5350
29	2670	2670	4810	3740	4280	2670	4810	5350
30	Alk.*	2140	Alk.*	3740	Alk.*	2140	Alk.*	2140
31	3210	2670	4810	2670	3210	2670	4810	2670
32	3210	2670	4810	3740	3210	2670	4280	3210
33	2140	3210	3740	2670	2670	2140	3740	3210
34	2140	2140	4280	3210	2670	2670	3740	3210
35	2140	2670	4280	3210	3740	2670	5350	3740
36	2670	2140	4280	4280	3210	2140	3740	2670
37	3740	2140	4810	4280	2670	2140	5350	2670
38	3210	2670	4280	3210	3740	2670	4280	3740
39	Alk.*	2140	Alk.*	3210	Alk.*	2670	Alk.*	3210
40	3210	3210	4810	2670	2670	2140	3740	3210
41	2670	2140	3740	2670	2670	1600	3740	2670
42	2140	2140	3740	2140	2140	1600	2670	2140
43	2140	2670	3740	2670	2140	2140	3210	4280
44	4280	2140	5350	6420	3740	3740	5350	4280
45	4280	2140	7490	6420	5890	3740	6960	4280
46	3210	2670	4280	2670	3740	2140	3740	4280
47	2670	2140	3740	2140	3210	1600	2670	2140
48	2140	2140	3210	2670	2140	1600	3210	2670

*Alkaline.

neutralizing effect shown in these two plots is also influenced by the nitrate of soda used in connection with the basic slag. Nitrate of soda also has an alkaline reaction in the soil due to the fact that the NO3 or nitrate part of the material is used up by the tree much faster than the NA or sodium portion.

This leads to more or less of an accumulation in the soil of the sodium element, which by combining with the carbonic acid gas of the soil water forms carbonate of soda, a material having an alkaline reaction.

The effect of nitrate of soda on an acid soil is also brought out by a study of the lime requirement of plots 15 and 48 which received this material as the source of nitrogen. In both plots the tendency of the nitrate of soda to decrease acidity is clearly shown. In plot 15 there is an actual decrease in the acid condition of the soil, while in plot 48 the soda has at least prevented an increase. In the soil of plot 42, receiving nitrate of potash and nitrate of soda, the tendency also is for the acidity to decrease.

ACID FERTILIZERS

The well known tendency of sulphate of ammonia to increase the acid condition of the soil is shown here in the majority of the plots receiving this material as the source of nitrogen. The plots showing the highest degree of acidity nearly all receive this material. It is true that some form of phosphoric acid and of potash were used on each plot in connection with the sulphate of ammonia and it might be argued that these materials were in part responsible for the acid condition present. The work of other investigators, however, where sulphate of ammonia was used alone, has shown that this material must be held as the chief cause of acidity. The absorption and nitrification of the ammonia of this material is comparatively rapid, being followed by its final utilization by the tree. This leaves the sulphuric acid portion in the soil, thus bringing about acid conditions. The potash of the muriate and sulphate of potash disappears much more slowly from the soil as the latter has the power of retaining for some considerable time the potash or basic element of these materials. Therefore, while the tendency of these materials would be to produce in the long run an acid condition, their action would be much slower than sulphate of ammonia. Similarly, it has been shown that the continuous use of acid phosphate does not increase acidity. On the contrary, it seems to decrease somewhat the acidity already present in the soil. The figures in Table 11 for the plots receiving floats or raw rock phosphate are not very conclusive. In three plots out of four sulphate of ammonia was used with the floats so that the influence of the latter on the acidity of the soil would be over-shadowed by that of the sulphate of ammonia. In general, however, it may be said that the use of floats would have a tendency to decrease the

acidity of the soil. The various forms of raw rock phosphate on the market contain more or less carbonate of lime as an impurity and their influence on the acid condition of the soil would be proportional to the amount of this material present.

EFFECT OF ACIDITY ON GROWTH

So far as could be noted an acid soil has no injurious effect on the growth of the orange tree. On some of the most acid plots in the grove the trees are vigorous and have made very good growth ranking well up among the best plots in the grove. These experiments would seem to show that so far as growth is concerned the citrus tree is very little influenced by an acid condition of the soil. Where a leguminous cover crop is desired during the rainy season the situation is different. During the early years of the experiment a beggarweed cover crop was allowed to occupy the soil during the summer months. After a time the soil became so acid that a fair stand could not be obtained and cowpeas and velvet beans were used instead. These crops appear to be much less susceptible to acidity than beggarweed and will do fairly well on soils on which the beggarweed almost refuses to grow. A study of Table 11 brings out the interesting fact that the acidity varies with the season, being greater in summer than in winter. The average number of pounds per acre of carbonate of lime required for the plots receiving the standard mixture of sulphate of ammonia, acid phosphate and high grade sulphate of potash is 4360 for the summer months and 3050 for the winter months, a difference of over half a ton. A probable explanation of this fact is that during the summer months the high temperatures and abundant rainfall lead to more rapid chemical and biological changes in the soil. This brings about greater decay of organic matter and more rapid transformations in the fertilizing materials present, resulting in a more rapid formation of acids.

NATURE OF SOIL ACIDITY

Soils may become acid or sour (1) thru an accumulation of organic acids produced in the decay of vegetable matter; (2) thru the depletion of the alkaline or basic constituents of the soil; (3) thru the addition of fertilizers leaving an acid residue in the soil. Most muck and peat soils are acid in character before being brought into cultivation. This is also true of many virgin soils of a more sandy nature. The decay of the vegetable matter present in such soils leads to the formation of organic acids, which tend to accumulate, especially if these soils are naturally

deficient in lime or if they are ill drained. After such soils are cleared, drained and brought under cultivation this acid condition disappears to a considerable extent, due to the aeration or introduction of oxygen into the soil thru cultural treatment. Where a crop of green material is turned under, as in the practice of green manuring, the soil may become acid for a time due to the formation of organic acids in the decay of the vegetable matter plowed under. In any case where acids are formed they lead to a depletion of the lime of the soil. It might be said that all soils tend to become acid in time due to the removal of lime and other basic materials in the drainage water. Both the lime in carbonate of lime and that in certain silicate compounds present in soils are dissolved by the soil acids and are leached out. When these forms of lime finally disappear from the soil an acid condition, so far as plant growth is concerned, is produced. An application of lime in some form is required to bring back the alkaline reaction. Florida high pine and flat woods soils, as a general rule, contain relatively small quantities of lime (usually very little if any in the carbonate form), yet the amount of this material appearing in the drainage water is surprising. In experiments carried out by the Florida Experiment Station it has been found that in the course of 10 months lime equivalent to 250 pounds of calcium carbonate has leached out and appeared in the drainage water from an acre of land. Such a loss of lime if continued for a few years would bring about acid conditions in the soil.

The use of fertilizers such as sulphate of ammonia, which leave an acid residue in the soil, is a frequent cause of soil acidity under Florida conditions. The acid residue combines with the lime of the soil and changes it to a soluble form which readily leaches out. In studying the loss of lime where different sources of ammonia were applied to the soil, the Experiment Station has found that where sulphate of ammonia was used the loss was over two times as much as where nitrate of soda was used. This tendency of nitrate of soda to decrease acidity, in other words, to conserve the lime of the soil, has already been mentioned in connection with the discussion of the loss of fertilizers by leaching.

An important feature in the use of these two materials is thus brought out. It is an advantage to use them together or alternately, as, for example, nitrate of soda as the source of ammonia in the spring and sulphate of ammonia in the summer.

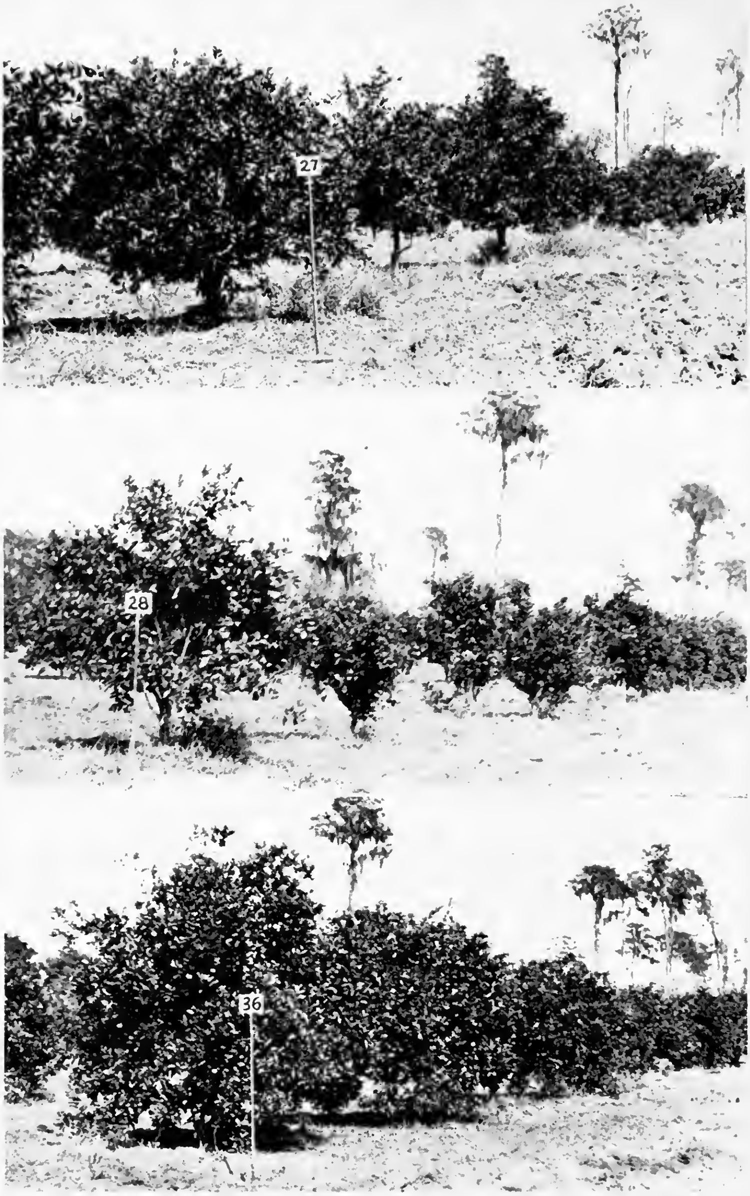

Fig. 9.—Phosphate plots

Plots 27 and 28 were fertilized with Thomas slag instead of acid phosphate. The source of nitrogen was nitrate of soda. Plot 28 received twice as much slag as plot 27. The trees in both these plots showed considerable frenching, plot 28 being much more severely affected. Most of the trees in plot 28 show the type of growth usually characteristic of badly frenched trees. Plot 36 received its phosphoric acid in the form of floats, four times the standard amount or 24 percent being used in the mixture. At the end of the experiment this plot ranked eighteenth. Plot 27 ranked thirty-fifth and plot 28 ranked forty-fourth.

Thus the nitrate of soda would counteract the acid condition brought about by the sulphate of ammonia. Other and greater advantages in thus using the two materials are discussed elsewhere.

LIME AND OTHER ALKALINE MATERIALS

Lime and other alkaline materials used in this experiment have proven distinctly injurious to growth. This injury consisted, in its mildest form, of a light attack of frenching; in the severest type, of chronic, severe frenching, partial defoliation, and a permanent retarding of growth, resulting in stunted undersized and unhealthy trees. The alkaline materials and the fertilizers used in connection with the plots were as follows:

Plot 11, 5-6-6, from sulphate of ammonia, acid phosphate, high grade sulphate of potash; ground limestone, 10 pounds per tree.

Plot 12, 5-6-6, same fertilizer treatment as plot 11, with limestone replaced by air-slaked lime, 5 pounds per tree.

Plot 21, 5-6-6, from cottonseed meal, acid phosphate, high-grade sulphate of potash; ground limestone, 10 pounds per tree.

Plot 27, 5-6-6, from nitrate of soda, Thomas slag, high-grade sulphate of potash.

Plot 28, 5-12-6, from same materials as plot 27.

Plot 30, 5-6-6, from nitrate of soda, acid phosphate, hard wood ashes.

Plot 39, 5-6-6, same treatment as plot 11.

The ground limestone and air-slaked lime were applied in the spring about two months after the spring application of fertilizers, and were distributed about the tree to about the same distance from the trunk as the fertilizers. The slag and hardwood ashes were applied mixed with the other fertilizers. The limestone and air-slaked lime were applied every year, beginning with 1909, until 1913, when the injury produced became quite noticeable and their use was discontinued for the remainder of the period of the experiment. The slag and ashes were used during the entire ten years.

During the early years of the experiment considerable frenching was found in all parts of the grove. As the trees suffered from dieback during these years the frenching was attributed to the same causes which produced the former disease. In 1913 it was noticed that the trees on some of the plots receiving alkaline materials were more severely frenched than the remainder of the grove. The worst injury was found on the ground limestone

Fig. 10.—Plots 11, 12 and 21, on which lime was used

The plots illustrated here were treated with lime in addition to the fertilizer. Plot 11 received the standard fertilizer mixture and ground limestone. Plot 21 received the standard mixture with the sulphate of ammonia replaced by cottonseed meal and ground limestone in addition. This plot showed much more frenching than plot 11. Plot 12 was fertilized with the standard mixture and air-slaked lime in addition. The trees showed very little frenching.

plots and on the plot receiving a double quantity of slag. The trees on the air-slaked lime plot and on the ashes plot also showed considerable frenching, which, however, almost completely disappeared after 1915, while the trees on the limestone and slag plots developed the more severe symptoms of the disease, such as the narrow pointed leaves, partial defoliation, and general unthrifty appearance. The disease continued to manifest itself in this aggravated form in these particular plots, until the closing out of the experiment. It seriously interfered with normal growth, the trees on the most severely affected plots appearing stunted, undersized and unhealthy.

Photographs of plots 11, 12, 21, 27 and 28 are reproduced in Figs. 9 and 10.

For a more detailed discussion of the injury induced by ground limestone, the reader is referred to Fla. Exp. Sta. Bulletin No. 137, Injury to Citrus Trees by Ground Limestone, by B. F. Floyd.

DIEBACK IN THE GROVE

In July, 1910, eighteen months after they had been set out, it was noticed that many of the trees exhibited the early stages of the disease known as dieback. At this time the symptoms were mainly the presence of gum pockets and the S-shaped branching. An examination showed about 78 percent of the trees thus affected. At the same time the trees presented a generally unhealthy appearance, much of the growth coming from the lower parts of the tree and from suckers. No measures for combatting the disease were adopted at this time, since it was considered very undesirable to introduce such complications in the experiment unless absolutely necessary. The grove was thoroly examined again in March, 1911, and in the fall of that year when it was evident that the disease had gained much headway and was causing serious damage. Table 12 shows the extent to which the grove was affected with the disease. In this table the number of the plot and the fertilizer treatment is given, in column I the number of trees in each plot showing symptoms of dieback in July 1910; in column II those showing symptoms in March 1911, and in column III those developing the symptoms in the growth made in the spring of 1911. (The writer is indebted to B. F. Floyd, Plant Physiologist, for this table.)

RELATION OF DISEASE TO FERTILIZER

The use of organic nitrogenous fertilizers has usually been regarded as a cause of dieback. A study of Table 12 however,

TABLE 12.—TREES AFFECTED BY DIEBACK
FERTILIZERS APPLIED

Plot	Different amounts	I	II	III
1	Half the standard	4	8	6
2	Standard	2	4	3
3	Double the standard	6	9	5
4	Four times the standard	9	8	7
5	Phosphoric acid and ammonia increased by one-half	9	8	4
6	Phosphoric acid and potash increased by one-half	8	9	5
7	Ammonia and potash increased by one-half	10	8	5
8	Phosphoric acid and potash decreased by one-half	9	10	6
9	Phosphoric acid and ammonia decreased by one-half	9	10	7
10	Ammonia and potash decreased by one-half	9	7	2
11	Standard and finely ground limestone	7	10	5
12	Standard and air-slacked lime	9	9	6
13	Standard and mulch	7	7	2
14	Standard	8	10	3
	Nitrogen from different sources			
15	From nitrate of soda	9	9	7
16	Half from nitrate of soda, and half from sulphate of ammonia	9	9	8
17	From dried blood	8	8	8
18	Half from sulphate of ammonia, and half from dried blood	9	8	4
19	Half from nitrate of soda, and half from dried blood	7	7	3
20	From cottonseed meal	4	4	0
21	From cottonseed meal. (With ground limestone.)	6	5	3
22	Half from cottonseed meal, and half from sulphate of ammonia	8	9	2
23	Half from cottonseed meal, and half from nitrate of soda	10	9	5
	Phosphoric acid from different sources			
24	From dissolved bone black	7	10	7
25	From steamed bone	10	9	4
26	From steamed bone. (Double amount.)	9	10	9
27	From Thomas' slag. (Nitrogen from nitrate of soda.)	8	8	4
28	From Thomas' slag. (Double amount. Nitrogen from nitrate of soda.)	4	6	4
29	From acid phosphate. (Potash, 7½ percent in June, 7½ percent in October and 3 percent in February.)	8	7	1
30	From acid phosphate. (Nitrogen from nitrate of soda. Potash from hardwood ashes.)	4	4	3
31	From acid phosphate. (Standard.)	10	10	7
32	From dissolved boneblack	8	9	9
33	From floats	10	10	8
34	From floats. (Double amount.)	9	10	6
35	From floats. (Four times amount.)	9	10	4
36	From floats. (Four times amount. Nitrogen from cottonseed meal.)	8	10	1
	Potash from different sources			
37	From low-grade sulphate	9	9	5
38	From muriate	9	8	3
39	From high-grade sulphate. (With ground limestone.)	10	10	7
40	From kainit	6	10	6
41	From high-grade sulphate. (Standard.)	7	9	7
42	From nitrate of potash. (Balance of nitrogen from nitrate of soda.)	8	9	6
	Different culture, etc.			
43	No fertilizer	3	4	0
44	Standard	7	10	8
45	Standard and mulch	8	8	4
46	Standard and clean culture	10	10	10
47	Nitrogen from dried blood. Clean culture	9	10	9
48	Nitrogen from nitrate of soda. Clean culture	7	6	3
	Total number of trees affected with dieback	373	411	241

brings out the fact that in this instance plots receiving a strictly mineral fertilizer were as badly affected with the disease as were those receiving cottonseed meal, dried blood and other organic sources of nitrogen. At no time during the progress of the disease could any definite relation be established between the disease and any particular fertilizer. In other words, the disease appeared to be entirely independent of the fertilizers used. It has been mentioned elsewhere that when they were set out three-fourths of a pound of steamed bone meal was used under each tree. It is possible that the organic nitrogen in the bone meal may have been the primary cause of the disease, but as every tree in the grove was treated in this way this theory was impossible of proof.

TREATMENT OF DIEBACK

In the spring of 1912 the disease had reached a serious stage and it became evident that measures for combatting it must be taken. The more advanced symptoms, such as bark excrescences, stained terminal branches, and multiple buds, were quite abundant, and a few trees were in such bad condition that it was necessary to replace them with others. The fertilizer applications for the spring and summer of 1912 were omitted and the trees were sprayed with Bordeaux mixture in February and April. In order to get at the effect of this spray in controlling the disease, the fifth tree in every plot was left unsprayed as a check. In the latter part of the year it was evident that the disease was much less prevalent than before the treatment. In January, 1913, B. F. Floyd made a careful examination of the

TABLE 13.—DIEBACK ON EXPERIMENTAL PLOTS IN JANUARY, 1913

	Gum Pockets	Stained Terminal Branches	Bark Excrescences	Multiple Buds	Ammoniated Fruit
Affected trees among sprayed	111	20	10	0	4
Affected trees among unsprayed	27	15	13	1	1
Percentage affected trees among sprayed	25.7	4.6	2.3	0	0.93
Percentage affected trees among unsprayed	56.2	31.3	27.1	2.1	2.1
Total number trees affected	138	35	23	1	5

trees for symptoms of dieback. Table 13 summarizes his notes made at that time. This table shows that over 56 percent of the unsprayed trees still showed dieback in the gum pocket stage as compared with 25.7 percent of the sprayed trees. While a total of 138 trees showed this symptom, none were at all severely affected or were being injured by the disease. The superficial symptoms such as stained terminal branches, bark excrescences and multiple buds, were quite scarce. It will be noted that in November, 1911, 81.7 percent of the trees showed gum pockets, while in January, 1913, the unsprayed trees showed 56.2 percent affected. This indicates a decrease in the disease during this period from causes other than the spray treatment. Probably the omission of the fertilizer application or other natural causes were of influence here in bringing about a decrease in the disease. Nevertheless it may be concluded from the data given that the Bordeaux treatment was quite effective in this instance in the control of dieback. In June, 1913, the trees appeared to be practically free from the disease, but in June, 1915, slight indications of it were again noted. Gum pockets were found on the new growth on 52 trees. They were not numerous on any of the trees, in most cases a careful search being necessary to find them. Of the 52 trees affected, 28 were the fifth tree in the plot, trees which had been left unsprayed at the time of treatment with Bordeaux mixture. No further treatment was given at this time and the symptoms of the disease disappeared from natural causes later in the year. From the end of the year 1915 on to the close of the experiment, no further trouble was experienced with the disease.

FREEZE OF 1917

During the first week of February, 1917, a cold wave swept over the state bringing freezing temperatures, especially on the 3rd and 4th, and causing considerable damage to the citrus and truck industries.

In the experimental grove temperatures of 21 on the 3rd, and 22 on the 4th were noted. A reproduction of the air and soil temperature records for the grove for the week ending February 5 is given in Fig. 11. In order to ascertain the extent and nature of the cold injury the grove was carefully examined during the first week of March. It was particularly desired to find out what effect, if any, the various fertilizer treatment had in making the trees more or less resistant to cold injury. The

criteria used in this study were the amount of defoliation, the number of twigs killed back and the distance to which they were killed, and the amount and character of the new growth produced after the freeze.

The individual plots showed considerable variation in the amount of injury caused by the cold, plots 28, 5, 7, 27, 21, 43 and 39 being the most seriously injured. At the time of the freeze the trees in these plots were in a weakened and unthrifty condition, owing to various causes, such as over-fertilization and the effect of alkaline materials, discussed in detail elsewhere. The fact that they were unthrifty was undoubtedly the cause of their more serious injury from cold. It is difficult to express the degree of injury in definite figures, but these trees showed approximately 85 percent defoliation, with 70 percent of the twigs killed back on the average about 9 inches. The new growth which was coming out was rather scanty and was weak in character.

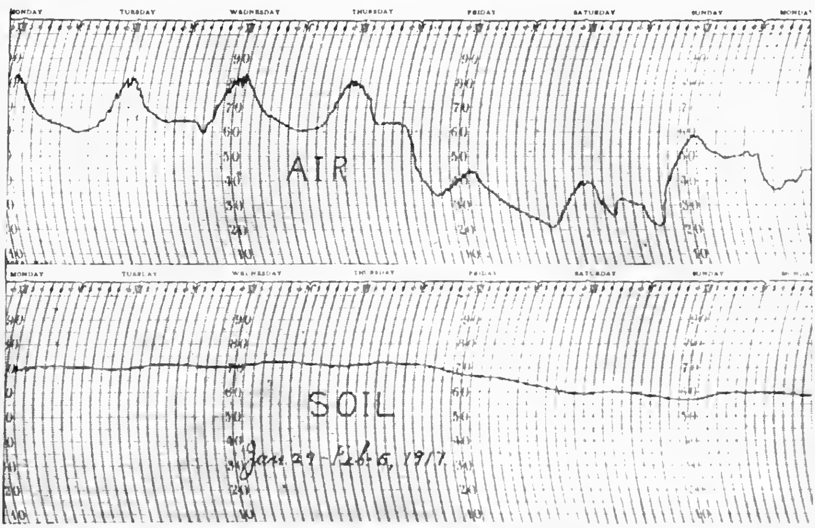

Fig. 11.—Reproduction of air and soil temperature records for the grove during the freeze of February, 1917

These figures may be compared with similar ones for plots showing the least amount of injury. Plots 2, 1, 47, 48, 12, 13 and 16 were selected for this comparison. These trees averaged approximately 65 percent defoliation with 30 percent of the twigs killed back a distance of about 5 inches. The new growth coming out was considerably more abundant and more thrifty

than on the other plots. These figures show that trees in good healthy condition are more able to withstand a freeze than are those in an unthrifty condition, and that the former make a quicker recovery. This statement was borne out by the general appearance of the trees and their subsequent behavior. No conclusive evidence could be obtained indicating that any special fertilizer treatment among those used on the better plots was more effective than another in making the trees resistant to frost.

CONCLUSIONS

1. In this experiment sulphate of ammonia, acid phosphate, and high-grade sulphate of potash gave somewhat better results as measured by increase in growth, than any other mixture.

2. Good results were obtained from the use of nitrate of soda as a source of ammonia, from steamed bone and floats as sources of phosphoric acid, and from the low-grade sulphate, hardwood ashes and the muriate, as sources of potash.

3. The use of ground limestone and Thomas slag have caused injury, indicated by frenching.

4. Clean cultivation thruout the year was of considerable benefit to young trees, but after a few years leads to a loss of soil organic matter. It is not a desirable practice with trees over five or six years old.

5. A large proportion of the phosphoric acid applied in the fertilizer is retained in the upper nine inches of soil. Practically none is leached out.

6. Much of the potash applied in the water-soluble form is retained by the soil.

7. Nitrogen, both in the organic and the in-organic form, is lost in large quantity by leaching as shown by the lysemeter experiments and by the analyses of the grove soils. There was a slight increase of nitrogen in all plots excepting the clean culture and the unfertilized ones.